MONTHLY WEATHER REVIEW

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AUGUST 1955

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First published in 1872, the Monthly Weather Review serves as a medium of publication for technical contributions in the field of meteorology, principally in the branches of synoptic and applied meteorology. In addition each issue contains an article descriptive of the atmospheric circulation during the month over the Northern Hemisphere with particular reference to the effect on weather in the United States. A second article deals with some noteworthy feature of the month's weather. Illustrated. Annual subscription: $3.00; additional for foreign mailing, $1.00; 30¢ per copy. Subscription to the *Review* does not include the *Supplements* which have been issued irregularly and are for sale separately.

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(Continued on inside back cover)

The Weather Bureau desires that the *Monthly Weather Review* serve as a medium of publication for original contributions within its field, but the publication of a contribution is not to be construed as official approval of the views expressed.

The issue for each month is published as promptly as monthly data can be assembled for preparation of the review of the weather of the month. In order to maintain the schedule with the Public Printer, no proofs will be sent to authors outside of Washington, D. C.

The printing of this publication has been approved by the Director of the Bureau of the Budget, February 9, 1955.

DEPARTMENT OF COMMERCE
SINCLAIR WEEKS, Secretary

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SECULAR FLUCTUATIONS IN VULNERABILITY TO TROPICAL CYCLONES IN AND OFF NEW ENGLAND

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ABSTRACT

Paths assumed by tropical cyclones in different fall seasons are related to the form of the prevailing mid-tropospheric general circulation. It is inferred that areas of vulnerability or invulnerability to these storms seem to be prescribed by the climatologically preferred circulation pattern during a given year, and for this reason expanded research along these lines could be highly rewarding. There is some indication that since the mid-thirties general circulation patterns have made east coast areas more vulnerable than during earlier years of the century.

1. INTRODUCTION

In two earlier papers [1, 2] the author discussed some of the long-range factors affecting the genesis and path of tropical cyclones. Coming shortly after the unwelcome visitations to northeastern United States of the damaging trio of hurricanes Carol, Edna, and Hazel, these reports excited considerable public interest. It is the purpose of this report to relate more specifically tropical cyclone occurrences in and just off New England to time-averaged climatic patterns of the general circulation of the order of a season. If such a connection exists, the problem popularly referred to as "hurricane cycles" becomes inextricably linked with the more general problem of climatic fluctuations.

For many years it has been known that the course of tropical cyclones is strongly influenced by the great centers of action. In a climatological sense the general recurvature of tropical storms in a path often resembling a parabola has been associated with the shape of the isobars around the western periphery of the subtropical anticyclones. Since the routine introduction of upper air charts in weather forecasting a number of studies have been carried on relating the motion of hurricanes to the broad-scale flow at one or more elevations in an attempt to find "the steering level." While attempts in this direction cannot be said to have been highly successful, the evidence clearly indicates a pronounced tendency for hurricane movement to be in the general direction of the broad-scale mid-tropospheric current in which the vortices are embedded. If the large-scale atmospheric flow patterns possess a mode then it becomes likely that any tropical cyclones which form and become embedded in this particular pattern will tend to follow a general preferred path. It has been recognized for almost a century that the great centers of action in the sea level pressure field undergo large variations from month to month, from season to season, and from year to year. Corresponding variations in the upper level components (ridges and troughs) of the planetary waves have more recently been demonstrated [3]. Inasmuch as the behavior of tropical cyclones appears to be explained somewhat more rationally and easily on the basis of upper air rather than sea level maps, it seems desirable to explore shorter period climatic fluctuations in these storms with time-averaged upper level charts. If the period of averaging is long, like a month or season, it becomes highly unlikely that hurricanes, which are few in number and small in extent, would materially influence the mean patterns.

Unfortunately, the file of adequate upper air charts for months or seasons is restricted to the short period dating

back to 1933. In the last fifteen years or so the source of this material has been conveniently available through readings made twice daily from routinely-prepared 700-mb. hemispheric analyses. These readings are interpolated at points of a close grid from contours, and then punched on cards, thereby facilitating the computation of means. In the decade of the 1930's other methods had to be used in order to extend the charts over ocean areas where very few direct upper air observations were available. Essentially the method employed consisted of: (1) constructing a mean sea level map for the desired period; (2) computing, plotting, and analyzing the field of anomalies (departures from the long-period normal) of these maps; (3) estimating from the anomalous components of flow the layer temperature departures (thicknesses) between 1000 and 700 mb.; and (4) computing and analyzing the field of 700-mb. height for a sufficiently close grid of points on the basis of the sea level pressure anomaly and the estimated thicknesses. In spite of some degree of subjectivity introduced by this method, its results are believed to be satisfactory for many climatological studies which require not exact but only approximate accuracy. For example, when the method was tested for the Pacific, Atlantic, and North American areas for four months when real (observed) means were available it was found that the average error was 60 feet, and the error was less than 100 feet 90 percent of the time. Besides, the patterns of the estimated contour surfaces correlated with the observed patterns with a value of 0.98, and the correlations of the departures from normal between the four pairs of computed and observed patterns were 0.77, 0.67, 0.72, and 0.92.

Inasmuch as we wish to study variations in tropical cyclone tracks and particularly the anomalous character of these tracks in certain months, it is helpful to obtain departures from normal of the mean maps. This has been done by subtracting the long-period normal from each of the monthly and seasonal means. The normals had to be determined for each month by different methods for different areas. For a detailed treatment the reader is referred to [4]. A seasonal mean chart and its anomalous pattern appears in figure 7.

The data for tropical storms were extracted from cyclone track charts published in the *Monthly Weather Review*, supplemented by recourse to individual weather maps when necessary.

2. THE GENERAL RELATIONSHIP BETWEEN PREFERRED PATHS OF TROPICAL CYCLONES AND SEASONAL PATTERNS OF THE GENERAL CIRCULATION

Year-to-year fluctuations in the number of tropical storms are well recognized. Tannehill [5], for example, displays a diagram showing the yearly variation in frequency of West Indian tropical cyclones from 1887, in which numbers range from 1 in 1890 to 21 in 1933. Equally interesting is the fact that certain regions are

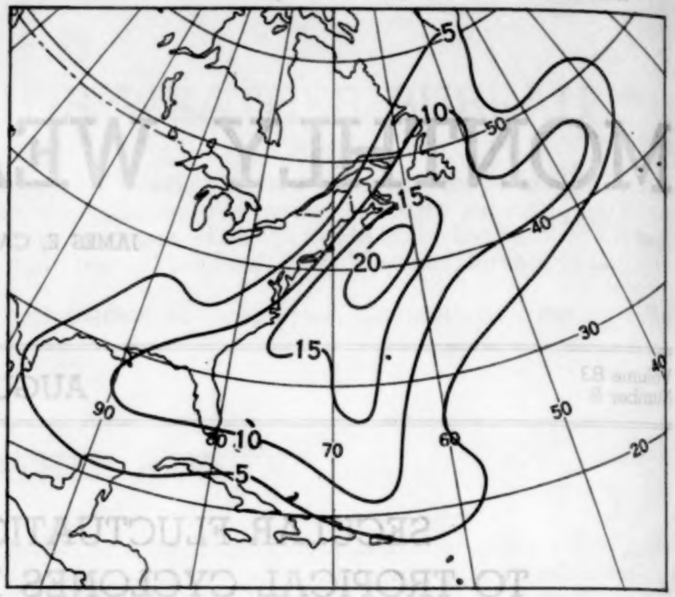

Figure 1.—Isopleths showing the number of tropical storm tracks entering 5° squares during the Septembers of 1935–1954.

relatively free of tropical cyclones during some autumns while other regions become unusually vulnerable. An extreme example of this kind is provided by the hurricane season of 1954 when these storms evaded southeastern United States but plagued the Northeast. It is unlikely that these year-to-year variations in number and path are random, particularly since the form and geographical placement of the planetary waves undergo great variations from one hurricane season to another. These varying patterns could set the stage for developing or inhibiting tropical cyclone formation and also for steering these storms once they are formed. A suggestion relating the climatic conditions to tropical cyclone formation was offered in an earlier article [1]. In the present paper however, the path-determining aspects will be the primary topic.

During the past twenty years tropical storms have traversed a broad domain covering eastern United States and the adjacent oceanic areas. From individual paths of these storms during the Septembers of 1935–1954 the number of storms affecting each 5° square has been plotted and analyzed in figure 1. The axes of maximum frequency (which are not necessarily most frequent paths) suggest that during this period the area around 40° N., 65° W. appears to have been the most vulnerable. Storms passing west of here are threats to New England, while those to the east are more likely to be misses. A criterion of vulnerability of the Northeast and adjacent waters was therefore set up according to the number of tropical cyclones in a given month which passed east of 40° N., 65° W. or were observed to pass to the west of this point (or through the point). The Appalachians were taken as a western boundary, and 40° W. as the eastern boundary of the area under consideration. During the Septembers

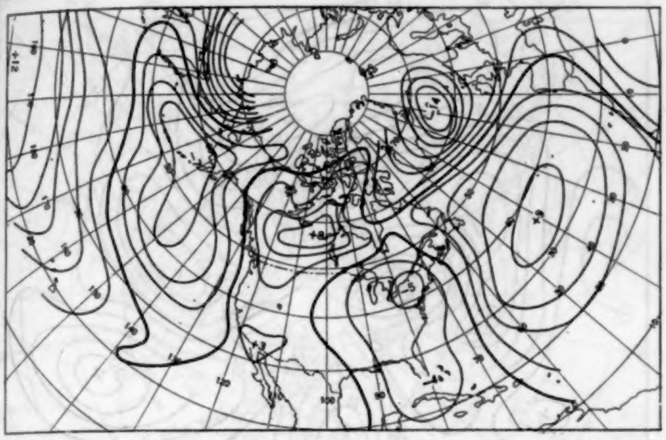

FIGURE 2.—Composite chart of the average departures from normal (in tens of feet) of 700-mb. height for those seven fall seasons (Sept., Oct., Nov.) of maximum tropical cyclone threat to New England (when three tropical storms moved west of 65° W. at 40° N. in September and October).

FIGURE 3.—Composite chart of the average departures from normal (in tens of feet) of 700-mb. height for those six fall seasons when no tropical storms threatened New England.

and Octobers of the years 1933–1954 the number of tropical cyclones which fitted into the latter category (threats to New England) is shown in table 1.

From the table it is apparent that during the falls of 1933, 1934, 1936, 1937, 1938, 1953, and 1954 tropical storms must have worried New England forecasters, while during the falls of 1939, 1941, 1947, 1949, 1951, and 1952 no major problems of this sort arose. The former series of years will be termed "maximum threat" years; the latter "minimum threat" years. November has been omitted in this tabulation since in that month tropical storms hardly ever penetrate close enough to New England to pose a threat. It appears that the years of maximum threat tend to occur in clusters, a fact possibly related to year-to-year persistence of general circulation anomalies.

TABLE 1.—*Tropical cyclones passing west of 40° N., 65° W. in Septembers and Octobers, 1933–1954*

Year	Number	Year	Number
1933	3	1044	2
1934	3	1945	1
1935	1	1946	1
1936	3	1947	0
1937	3	1948	1
1938	3	1949	0
1939	0	1950	1
1040	2	1951	0
1041	0	1952	0
1042	1	1953	3
1043	1	1954	*3

*Includes hurricane Carol which passed August 31.

A composite chart of the departures from normal of the 700-mb. surface for the autumns [1] of the hurricane-threat years is shown in figure 2. This chart is derived from the individual seasonal charts (means of Septembers, Octobers, and Novembers). The inclusion of so much data (21 months) makes it highly unlikely that the pattern of anomaly would be materially affected by tropical storms of these years, which, after all, occur on a small number of days in given regions and occupy a relatively small portion of the map. It is believed, therefore, that the anomalous features of the general circulation shown in figure 2 are associated with basic recurrences of similar large-scale features, and that these features tend to control the paths of the tropical vortices as well as other disturbances. The well-defined character of the anomalous areas in figure 2 is due to persistent recurrence during several seasons. If a smilar map is prepared for the years when no tropical storms threatened, the corresponding pattern (fig. 3), while somewhat less distinctive, also possesses some interesting large-scale features.

Several features of figure 2 are noteworthy. First, the centers of anomaly are extensive, having dimensions roughly of the order of the planetary ridges and troughs which appear on monthly mean charts. Secondly, there appear to be compensations in that large positive anomalies in one area are balanced by negative areas elsewhere. In regard to the problem of hurricane steering, perhaps the first striking item in connection with figure 2 is the negative (−5) anomaly centered just inland from the Atlantic Coast and the associated anomalous southerly component off the Atlantic Seaboard. This is evidently the immediate influence which, once the tropical storm moves northward from the West Indian area, provides for its assumption of a farther westward path than normal after passing Cape Hatteras. Referring to the autumn normal 700-mb. circulation (fig. 4) it is clear that the negative anomaly in effect represents deepening of the trough normally found over eastern United States. During periods of tropical storm threat to New England an amplification of the normal planetary wave pattern occurs, as may be seen by

[1] Seasonal charts were used rather than September-October means because of their availability. In subsequent studies currently contemplated, means of August, September, and October comprising almost the entire hurricane season, will be prepared and studied.

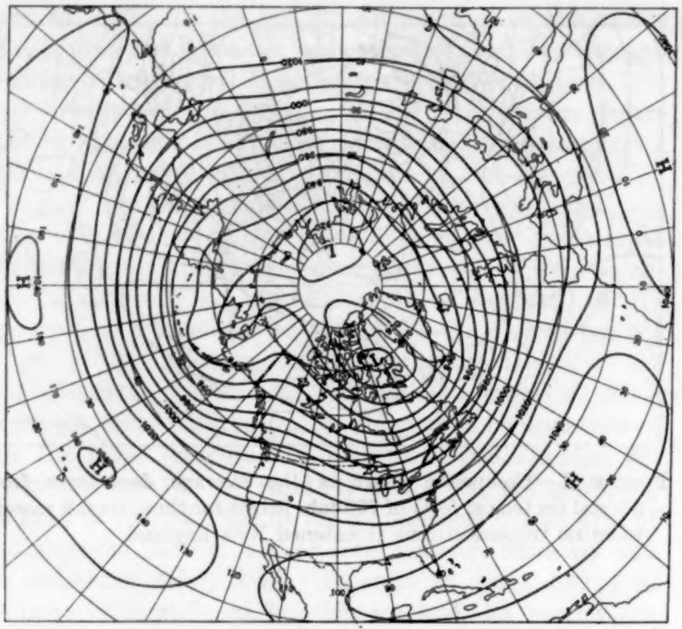

FIGURE 4.—Normal 700-mb. chart for autumn (Sept., Oct., and Nov.). Labeled in tens of feet.

superimposing the anomalies of figure 2 on the normal pattern of figure 4. Effectively then, meridional motion of east coast storms, extratropical as well as tropical, becomes favored, making the projecting land areas north of Cape Hatteras more vulnerable.

While the science of meteorology up to now has not been able to explain the ultimate cause of such climatic anomalies as appear in figure 2, considerable knowledge of the interdependence between anomalies in distant portions of the hemisphere has been gained. In fact, one of the best known of these interrelationships, Sir Gilbert Walker's North Atlantic oscillation, where negative anomalies over Iceland usually go with positive anomalies over the Azores, is indicated in figure 2. More extensive work exploring these "teleconnections" for mid-tropospheric levels has been carried on by Martin [6]. Essentially, Martin's work involved dividing several years of 5-day mean 700-mb. maps and anomalies into seasons and stratifying the data so that he could determine the probability of sign of the anomaly in various areas of the hemisphere if one selected area was characterized by a large anomaly (either positive or negative). In a sense his charts may be considered as empirically derived spheres of influence for they incorporate the average influence of differential heating, mountains, and other factors on the flow patterns. Since Martin used selected points 20° of longitude apart for three latitudes (30° N., 40° N., and 50° N.) and two seasons, winter and summer, he obtained a total of 216 charts. One may scan these charts for the key (selection) areas indicated by the anomalous areas in figure 2 in order to see what areas adjacent and remote from the key area would be characterized by large probability centers, and

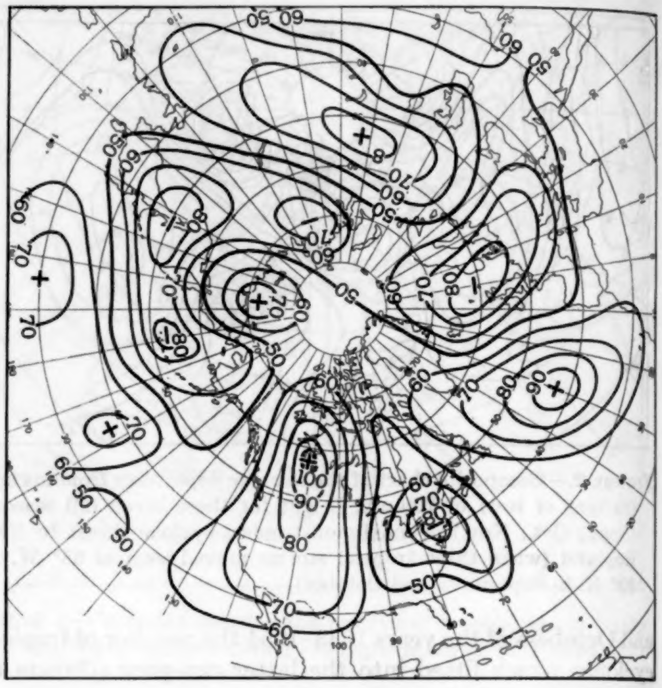

FIGURE 5.—Percentage frequency of sign of 5-day mean 700-mb. height anomaly for all wintertime cases when an axis of maximum positive anomaly lay between 110° W. and 120° W. near 60° N. (From [6].)

thus make comparison with figure 2.[2] Doing this, one finds that the chart most resembling figure 2 is the one on which the key area is positive and near 60° N. between 110° and 120° W. in winter. This chart is reproduced in figure 5. The similarity in pattern to figure 2 is quite striking, especially with reference to the negative center in eastern United States and the position and orientation of the Atlantic anomalous cells. Other charts selected on the basis of a positive key area for the same longitudes at 50° N. in winter and also for summertime have similarities, but not as pronounced as those of figure 5. At any rate, selecting on the basis of the northwest Canadian area seems to define a pattern most similar to the tropical cyclone threat pattern shown in figure 2. The inference suggested by this correspondence is that the northwestern Canadian area may be one of the key areas to consider in estimating the vulnerability of the Northeast to tropical storms.

Although the above conclusion is based on seasonal means there are shorter-period indications of a similar nature. In the first place, vorticity considerations imply that when the west Canadian ridge builds, its downstream neighboring trough usually deepens—thereby favoring increased southerly flow in its advance which could deflect the course of a captured tropical cyclone. Secondly, any tendency for north to northeast upper level components emanating from the central Canadian region encourages

[2] It can be shown statistically that higher probabilities usually go with higher mean values of the anomaly itself, so that in a general sense, isolines of probability may be interpreted similarly to isolines of anomaly.

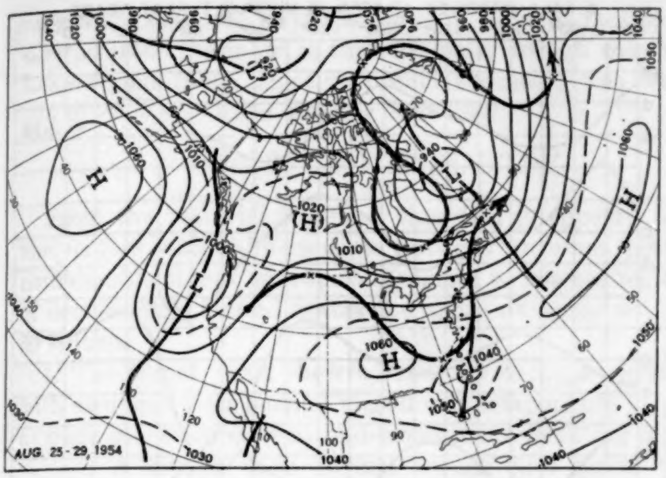

FIGURE 6.—Five-day mean 700-mb. chart for August 25-29, 1954, immediately preceding penetration of hurricane Carol into New England. Note constant vorticity trajectories (heavy curves) suggesting creation of trough conditions over eastern North America. Path of Carol given by dotted line.

the formation and deepening of troughs in the Great Lakes region, which in turn favors more northward movement of east coast cyclones.

An excellent example of this effect is afforded by hurricane Carol, 1954. In the 5-day period just preceding its northward acceleration (fig. 6) the west Canadian ridge had built up strongly and constant vorticity paths from both north and west sympathetically indicated the formation of a deep trough in and south of the Lake region, which indeed did subsequently form and steered Carol almost due north into New England [7].

It is not meant to imply that the entire general circulation depends on conditions in the west Canadian area, for other "centers of action" are also important. If for some unknown reason the Atlantic anticyclone is weak and the westerlies penetrate strongly into the New England region, tropical cyclones are apt to be steered out to sea without striking land. However, in view of the suggested dependence of other circulations upon a strong positive anomaly over western Canada, a risk factor arises which cannot be dismissed lightly. This risk is of course dependent on the existence of tropical storms which may be captured by the deep polar trough. From the extension of the eastern United States negative anomaly well into the tropics (fig. 2) it appears that this average threat pattern also favors genesis of tropical storms. Such a favorable climate for hurricane genesis may be brought about in the manner suggested in the earlier report [1] i. e., by creating large areas of static instability and general cyclonic vorticity at the base of deep polar troughs.

An example of an individual seasonal pattern of maximum threat (1937) is shown in figure 7. It was indeed fortunate that the hurricanes glanced off New England without striking land, although in the following year when a similar but more aggravated pattern occurred, the great hurricane of 1938 struck.

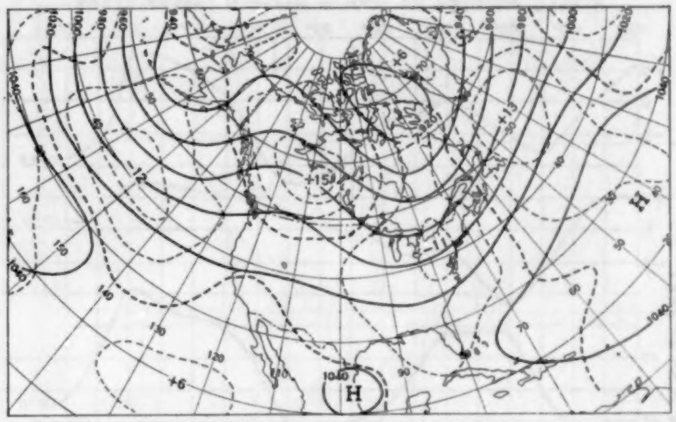

FIGURE 7.—Mean 700-mb. contours (solid lines) and anomalies (broken lines) for autumn 1937, a maximum threat pattern for the Northeast.

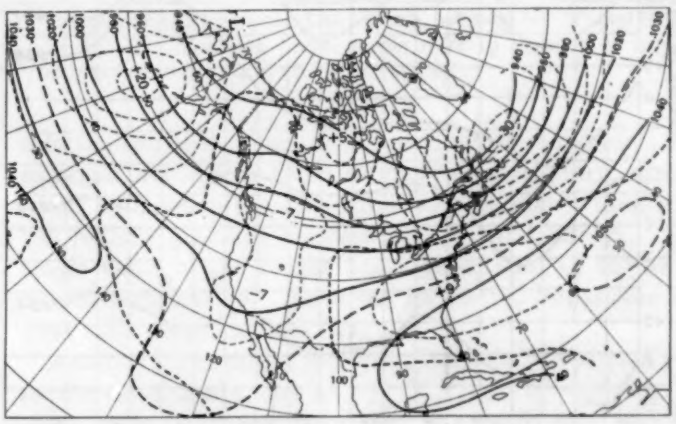

FIGURE 8.—Mean 700-mb. contours (solid lines) and anomalies (broken lines) for autumn 1941, a climatic pattern highly unfavorable for tropical cyclone penetration into New England.

The circulation patterns associated with a complete lack of tropical cyclones passing west of 65° W. at 40° N., i. e., the falls of 1939, 1941, 1947, 1949, 1951, and 1952, appear to be somewhat less homogeneous than the threat cases. Part of the reason for this is that different types of patterns may be unfavorable for genesis of West Indian tropical cyclones, may steer them beyond the confines of the area treated (40° W.) by the time they reach 40° N., or may steer them inland south of 40° N. to be rapidly dissipated over land. In all three cases the New England area remains invulnerable. In the fall of 1941, for example (fig. 8), the westerlies were anomalously strong over the Northeast coast and cyclones caught in this stream would probably be carried out to sea before reaching 40° N. However, the strong zonally-oriented positive anomaly extending from southeastern United States through Bermuda inhibited northward penetration and steered the cyclones westward into the Gulf of Mexico. Thus no tropical cyclones were recorded in the fall of 1941 passing 40° N. latitude in the western Atlantic.

Although the patterns of the minimum threat years seem to be less homogeneous than those of the maximum

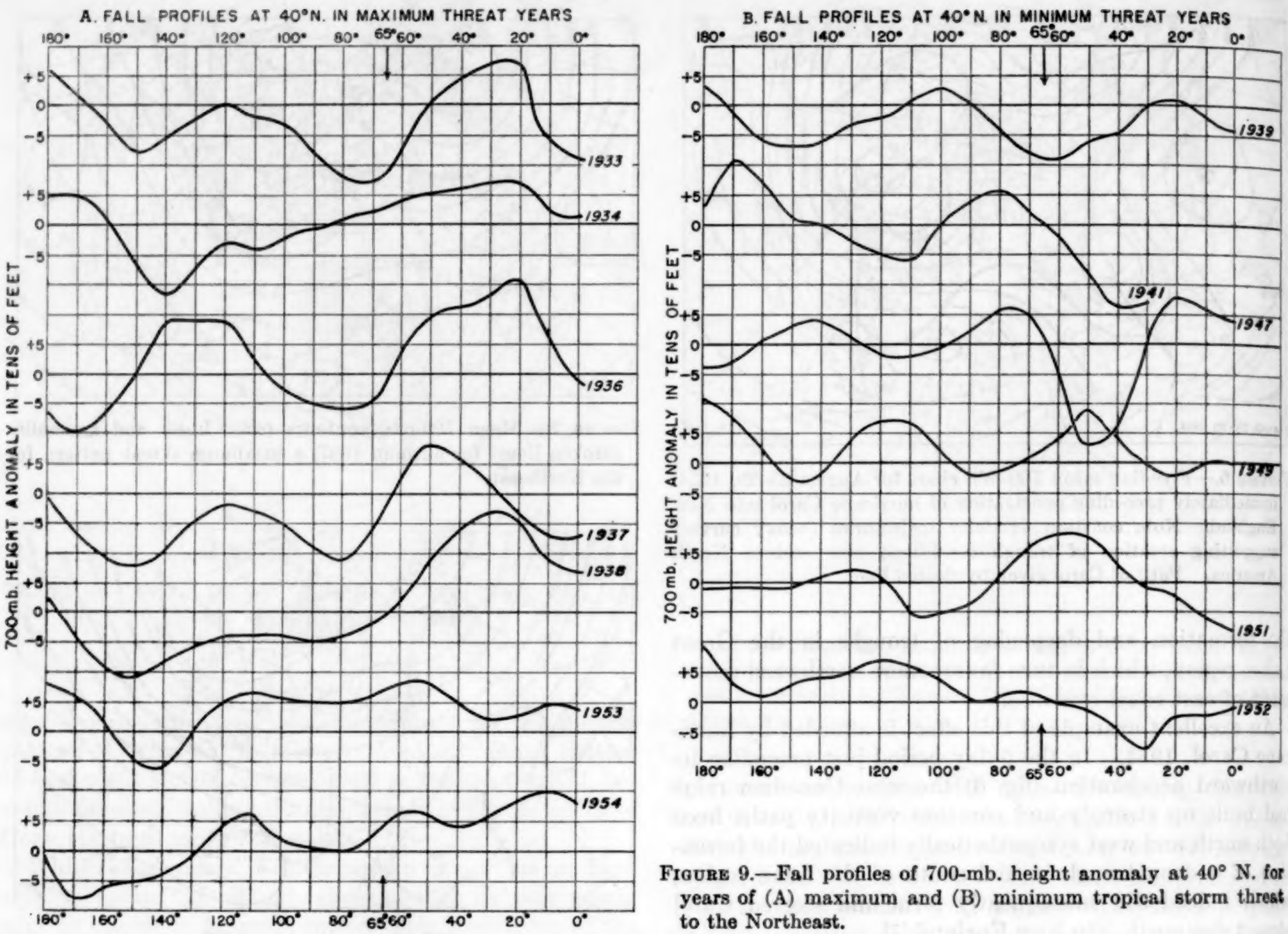

Figure 9.—Fall profiles of 700-mb. height anomaly at 40° N. for years of (A) maximum and (B) minimum tropical storm threat to the Northeast.

threat years their mean (fig. 3) displays some characteristic features. Comparing figures 2 and 3, the more striking differences are:

1. In the Atlantic in the minimum threat years a deep and extensive negative anomaly replaces the positive found in the maximum threat years.

2. A net positive anomaly exists over eastern United States rather than a negative.

Both the above features are unfavorable to northward steering by the Atlantic subtropical anticyclone.

3. The absence of a strong northwest Canadian positive anomaly makes less favorable the transport of cyclonic vorticity to encourage a trough in the Lake Region.

When superimposed upon the normal fall pattern (fig. 4) the net result of the mean anomalies of minimum threat years is a wave pattern of less amplitude than normal, particularly so compared to the mean of maximum threat years.

On the average, the years in which no September and October tropical cyclones passed westward of 40° N., 65° W. were also deficient in tropical storms over the entire western Atlantic (west of 40° W.). Thus in the seven no-threat years only about one-half the number of tropical cyclones per year (1.7) were observed to pass 40° N. as did in threat years (3.9). Apparently the patterns favoring meridional and thus farther than normal westward motion of these storms also favor cyclone development in the general area of the West Indies. This possibility has been mentioned in connection with the composite anomaly shown in figure 2, where one obtains the suggestion of deep polar troughs along the east coast which can penetrate to low latitudes.

Profiles of 700-mb. height anomaly along 40° N. for the maximum and minimum threat cases are reproduced in figure 9. In all the threat cases it will be noted that the anomalous gradient is directed from south to north at 65° W. However in the no-threat years the reverse gradient is present at this longitude on only four of the six cases, and the 1949 and 1951 profiles are quite the inverse of 1939, 1941, and 1947 profiles. In examining the more complete maps (not reproduced) it becomes clear that in 1951 the polar trough was entirely lacking in the east (note large positive profile anomaly) as was the positive anomalous area in Northwest Canada. This positive area often acts like a block to tropical storms, forcing them to skirt it by striking inland farther south and rapidly dissipating, or by moving off to sea without striking land at all. While the situation in 1949 is more

difficult to diagnose, perhaps the most obvious fact to be derived from the maps is that the polar trough over the Lake region (note negative profile anomaly) was weak and did not penetrate into the Southeast.

3. INDICES OF VULNERABILITY

From the material reviewed thus far, it appears that the factors which differentiate between autumns posing considerable threat of tropical cyclones to coastal regions of northeastern United States and those which do not are as follows.

1. The threat years show a tendency to be associated with stronger than normal meridional components in the average planetary flow in mid-troposphere resulting in:
   - (a) A deeper than normal trough just inside the United States coast, the negative anomaly penetrating into the Tropics.
   - (b) Stronger than normal neighboring ridges in the western United States and especially Canada and in the central Atlantic.

     Both of these factors represent essentially an amplification of the pre-existing normal planetary wave pattern.
   - (c) A Canadian anomaly pattern which favors increased north or northeast components north of the Lake region.
   - (d) A deeper than normal Icelandic Low in about its normal position.
   - (e) A deeper than normal trough off the west coast of United States (this is associated with the stronger than normal ridge over western United States).

2. On the other hand, the seasonal patterns associated with little or no threat to coastal regions of the Northeast are those which nullify in some way the steering effect of the eastern United States trough. This is usually effected by a marked positive anomaly here which is often associated with compensating negative anomalies over western United States and Canada and in the central Atlantic. The net effect results in a flatter than normal planetary wave pattern over North America and adjacent waters thereby providing for more eastward steering of any captured disturbances and also for reduced polar penetrations into the Tropics which may be important for the genesis of such storms. In the case of large positive anomalies near or over New England, tropical storms may be forced inland to the south and rapidly dissipate.

It is perhaps fascinating to design an index which relates the number of threats to the Northeast to the above-mentioned parameters.

Perhaps two of the simplest indices are the departure from normal of the 700-mb. height at 40° N., 50° W., which in effect measures the nature of the blocking ridge off the Atlantic coast, and the difference between the height anomalies between 60° W. and 80° W. along 40° N., which measures the anomalous steering gradient. From these plots, shown in figure 10, it is clear that part of the

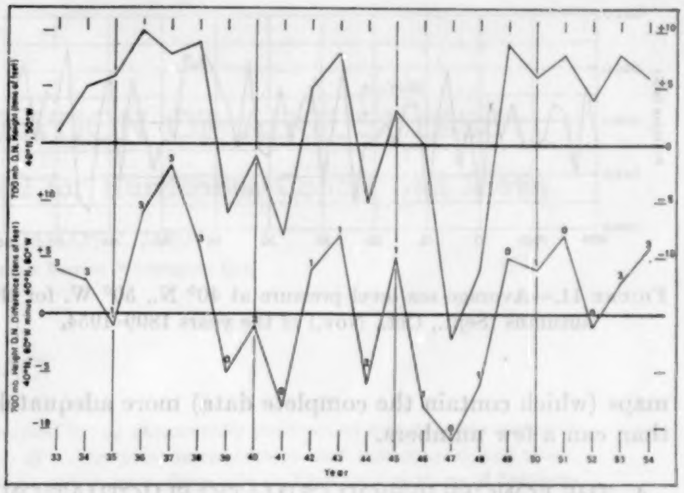

FIGURE 10.—(Upper curve) 700-mb. height anomaly at 40° N., 50° W. for successive autumns. (Lower curve) Difference in anomalous height gradient at 700 mb. between 60° W. and 80° W. at 40° N. Numbers beside curve refer to number of tropical storms passing west of 65° W. at 40° N.

information of the maps is captured by these indices. For example, about four times as many tropical storm threats occur with south-to-north anomalous gradients than with the reverse gradient between 60° W. and 80° W. The single value of the height anomaly at 40° N., 50° W. is similarly indicative. However, for an individual case like 1944 such simple indices fail.

Another index might incorporate the height anomaly in northwest Canada, say at 55° N., 105° W. (see fig. 2), along with the anomalies at 40° N., 80° W. and 40° N., 50° W. Giving equal weight to the three points, and considering the Canadian and Atlantic points contributing in a positive sense to threat when they are positive, but reversing the sign of the 40° N., 80° W. point, we can obtain summations which might also serve as a threat index. Table 2 summarizes the averages of this index for 0, 1, 2, and 3 storms passing west of 65° W. at 40° N.

Besides, twice as many threats occurred with indices above their average values for all seasons as with below average indices.

Apparently, even such crude and simple indices capture some of the large-scale features described above.

While further attempts to develop an objective index might improve the stratification it is believed that such an exercise would be unprofitable, because the trained synoptic meteorologist can probably evaluate the actual

TABLE 2.—*Average index (combination of height anomaly at three selected points—see text) for 0, 1, 2, and 3 threats (storms passing west of 65° W. at 40° N.)*

Number of threats	Average index	Number of cases
0	−4.0	6
1	7.0	5
2	13.3	4
3	18.7	7

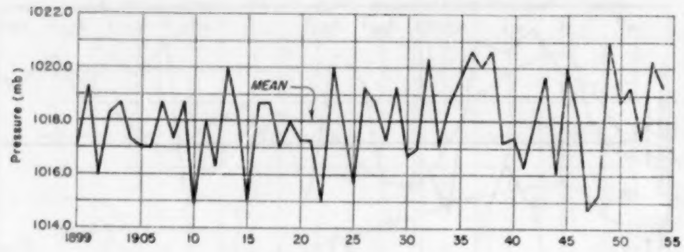

FIGURE 11.—Average sea level pressure at 40° N., 50° W. for the autumns (Sept., Oct., Nov.) of the years 1899–1954.

maps (which contain the complete data) more adequately than can a few numbers.

4. THE LONGER-PERIOD CLIMATIC FLUCTUATION

As Bergeron [8] has inferred, there is no reason why hurricanes, as well as temperature and rainfall, should not undergo long-period climatic fluctuations. The author [2] attempted to relate the increased vulnerability of late years along the Atlantic coast to the climatic warming there, showing that both the more northward steering of hurricanes and the abnormal warmth of recent winters were associated with a greater prevalence than normal of southerly flow with a maritime component in the lower troposphere.

Unfortunately it is not possible to extend the file of upper air charts beyond 1933, and therefore, the thesis advanced in this paper cannot be tested further. However, over ocean areas well removed from the continents it is well known to the synoptic analyst that there is a fairly good correlation in any one season between pressures at sea level and at 3 km. In monthly or seasonal means this correlation may run quite high. For example, for the 20 years 1933–38 and 1941–54 when good data were available, the correlation between seasonal means of sea level pressure and 700-mb. height at 40° N., 50° W. comes out to be 0.93. Inasmuch as this point captures some of the large-scale steering features described in this report (see fig. 2) a plot of the autumnal means for the period 1899 to date was made (fig. 11) using the historical map series [9] for the earlier years up to 1939. While one might fit a sloping upward trend line to these data it appears to the author that a somewhat different regime began around 1933. The difference shows up not so much in the means, which for 1933 to 1954 are 1018.4 mb. against 1017.7 mb. for the period from 1899 to 1932, but rather in the frequency of points above the long-period average. For example, while from 1899 to 1932 there were about an equal number of points lying above (47%) and below (53%) the average for the total period, after 1933 there were 66 percent above the average. It is also obvious that the frequency of high peaks has increased. It is unlikely that these differences are due to inadequate data of the earlier years of historical maps, for this area was reasonably well covered by reporting ships. Besides, such a trend is in keeping with the recent climatic warming along the east coast.

Thus we may be in a new climatic epoch as far as vulnerability of the Northeast to tropical storms is concerned. But before any predictions of years to come can be made there must be an understanding of what produces climatic fluctuations of the general circulation. We have not treated this vast problem in this paper, and in describing the anomalous features of the circulation which influence east coast vulnerability special care has been taken to avoid discussing ultimate causality. It could be, for example, that the strengthened Atlantic upper-level ridge which is associated with threat cases is in part a reaction from the well developed Icelandic trough, but as in all studies of long-period teleconnections it is not possible at present to disentangle the maze of entwined forces and resonant perturbations. Until this problem is solved, prediction of climatic fluctuations in hurricanes, as well as other elements, for more than a season in advance will probably enjoy little success. However, the moderate success obtained in 30-day forecasting can offer helpful clues.

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THE WEATHER AND CIRCULATION OF AUGUST 1955[1]

Including the Climatological Background for Hurricanes Connie and Diane

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ABSTRACT

The general circulation during August 1955 was characterized by an abnormally contracted circumpolar westerly whirl and an associated northward displacement of the belt of subtropical anticyclones and subtropical easterlies. While this zonal circulation was similar in many respects to that of the preceding July and led to a pattern of temperature anomaly over the United States similar to July's, the rainfall differed tremendously, particularly over the Northeast where flood-producing rains associated with hurricanes Connie and Diane replaced a regime of drought. The differences between July and August are accounted for by westward displacements of the centers of action coupled with markedly similar anomalous zonal circulations (i. e., displaced poleward). The early onset of the hurricane season is attributed to the premature northward displacement of the subtropical belt of anticyclones. The unprecedented precipitation associated with hurricanes Connie and Diane is believed to be partially related to injection of abnormally moist tropical air from an appreciably warmer than normal sea surface.

1. CLIMATIC BACKGROUND FOR HURRICANES CONNIE AND DIANE

Climatic fluctuations of short and long duration in temperature, precipitation, and other meteorological elements are accepted by meteorologists as characteristic phenomena of the atmosphere. Since the genesis and paths assumed by tropical storms are extremely sensitive to a number of factors it is not surprising that there are great fluctuations in frequency, character, and paths of hurricanes. The senior author of this paper has tried to elucidate this point in connection with month-to-month and year-to-year fluctuations in the vulnerability of the Atlantic Seaboard to tropical storms [1].

In this connection the statements expressed by Bergeron [2] are especially noteworthy:

> Another problem, of much more far-reaching consequences, presents itself. What kind of secular changes may have existed in the frequency and intensity of the hurricane vortices on our Earth? And what changes may be expected in future? We know nothing about these things, but I hope that this paper may have shown that even quite a small change in the different factors controlling the life history of a hurricane may produce, or may have produced, great changes in the paths of hurricanes and in their frequency and intensity. A minor alteration in the surface temperature of the sun, in the general composition of the earth's atmosphere, or in the rotation of the earth, might be able to change considerably the energy balance and the balance of forces within such a delicate mechanism as the tropical hurricane. During certain geological epochs, hurricanes may have been just as frequent as the cyclones of our latitudes, or they may have occurred all over the oceans and within all coastal regions, and they may have been even more violent than nowadays. During other periods they may have been lacking altogether. In studying paleo-climatic and paleo-biological phenomena, especially along the coasts of previous geological epochs, it may be wise to consider such possibilities.

The 1955 crop of hurricanes contained two early season storms, Connie and Diane, which will furnish ample material for several meteorological investigations. It is hoped that these investigations, as well as researches in connection with hurricanes in general, will not ignore the long-period aspects of the general circulation which in effect set the stage for smaller-scale phenomena that subsequently develop.

In the case of hurricanes Connie and Diane two climatological factors bearing on their formation and course appear highly pertinent:

1. The planetary zonal wind systems during the two months preceding their formation were appreciably farther north than normal, and
2. The regions in which the zonal wind systems were displaced farthest northward were over eastern North America, the eastern Atlantic and Europe, and the west central Pacific.

These displacements in August are illuminated by the zonal wind speed diagrams shown in figures 1 and 2A. The abnormal northward displacement of zonal wind systems was observed starting as early as late June. For example, 700-mb. zonal wind speed profiles for the period from mid-June to mid-July (not shown) showed a peak at 52° N.—a full 10° north of normal. The northward displacement during July was associated with record-breaking and sustained heat and dryness over northeast portions of the country, but relatively cool, wet conditions over the Southeast—a topic treated at length in the preceding article of this series [3].

[1] See Charts I-XV following p. 184 for analyzed climatological data for the month.

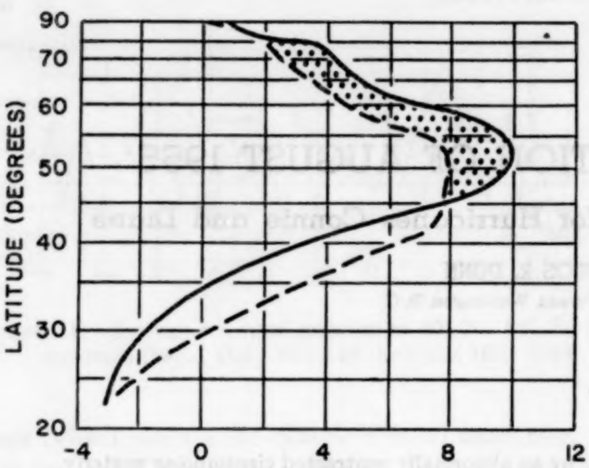

FIGURE 1.—Mean 700-mb. zonal wind speed profile in the Western Hemisphere (0° westward to 180°) for August 1955. An abnormally contracted circumpolar vortex was associated with above normal westerlies north of 45° N. (stippled area) and subnormal westerlies to the south. Note the strong easterlies in the subtropics.

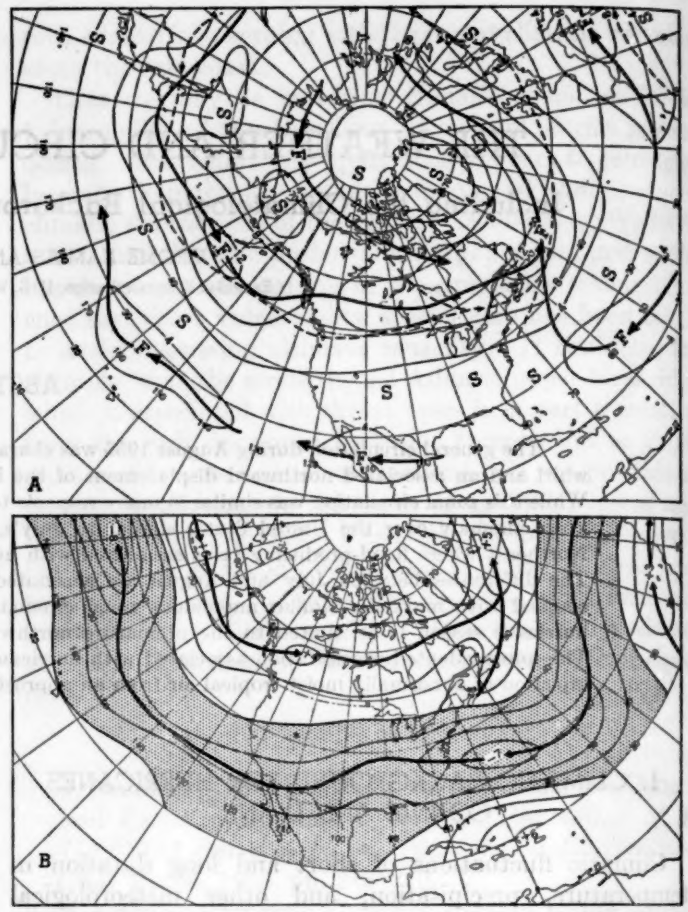

FIGURE 2.—(A) Mean 700-mb. isotachs and (B) departure from normal of zonal wind speed component (both in meters per second) for August 1955. Solid arrows in (A) indicate positions of mean 700-mb. jet axes, and broken arrows their normal August positions. The westerly jet was north of its normal location at all longitudes in the Western Hemisphere. Solid arrows in (B) delineate axes of maximum easterly and westerly anomalous flow with westerlies considered positive.

Since the subtropical Atlantic anticyclone was well north of normal and associated with a compensating deficit of mass in lower latitudes, it is perhaps not surprising that the Atlantic hurricane season got under way early with detection of hurricane Connie on August 4. In other words, the northward seasonal march of the planetary zonal circulation was advanced ahead of normal, so that events (i. e., hurricanes) which most frequently get under way in late August could get an early start. In this respect a quotation from C. L. Ray [4] seems pertinent:

> Spring and summer pressure deviations in the North Atlantic, as indicated by the pressure at San Juan, have an inverse relation to tropical storm frequencies of the summer and autumn months. This is best indicated where pressure continues above normal from May through July, but is also related definitely to the July departure considered singly, and also as early as April-May.

This statement of Ray's reflects the summer persistence of anomalous features of the general circulation over southern portions of the North Atlantic. Indeed persistence of 700-mb. height anomalies over this hurricane breeding area is especially pronounced from July through September (see fig. 3 A and B from [5]). Whatever the ultimate cause of this persistence, it seems clear that the same factors which led to the great frequency of easterly waves which affected southeastern United States in July [3] also favored the early incidence of hurricanes in August.

While hurricane Connie was first reported on August 4 at about 16.6° N. and 48.0° W., there is some indication that it developed off North Africa some time earlier. At any rate planetary wave forms over the North Atlantic evolved in a manner which the authors have come to associate with tropical storm formation. Thus in late July the ridge of the Azores upper level anticyclone thrust strongly northeastward into Europe, thereby introducing a northeasterly flow which, through vorticity flux, lead to an anomalously sharp and deep trough extending along the Spanish and African coasts (see fig. 4 A and B). It was probably at the base of this trough that Connie developed—its formation encouraged by the injection of cyclonic vorticity from the north and by associated vertical destabilization processes as discussed in an earlier report [6]. If this hypothesis is correct, the frequency of tropical storms of the Cape Verde type may well depend upon the degree of development or suppression of the protruding Azores ridge to the north.

While the physical explanation of persistence of circulation features from July through August lies outside the scope of this report, there may have been some resultant effects on water temperatures off the Atlantic Seaboard which could have had a profound bearing on the hurricanes Connie and Diane—especially regarding their copious rainfall.

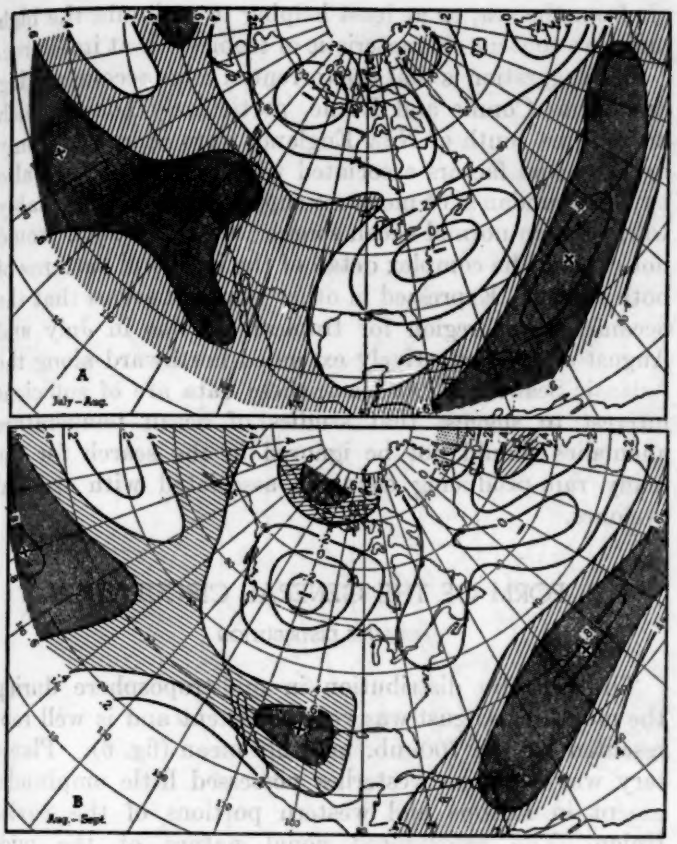

FIGURE 3.—Isopleths of one-month lag correlation between mean monthly heights of the 700-mb. surface for period 1932–1951 (from [5]). Persistence over southern portions of the North Atlantic is especially pronounced from July to September.

The senior author of this report spent part of the past summer at Woods Hole on Cape Cod, Massachusetts. On this seacoast peninsula, afternoon sea breezes attended by comfortable temperatures and humidities are the rule. However, in the month preceding hurricanes Connie and Diane the sea breezes were oppressive to a degree rarely felt. Although no complete observations are available from this point the temperature and humidity observations from Boston and Hartford (table 1) indicate the abnormal warmth and moisture.

It seems probable that such high temperatures and particularly high moisture contents may have been due in part to abnormally warm waters off the northeast coast.

TABLE 1.—*July and August 1955 surface temperature and moisture content at Boston and Hartford*

	1955	Mean surface temperature °F. (to nearest degree)		Mixing ratio (g/kg)	
		Observed	Normal	Mean	Departure from normal
Boston, Mass.	July	77	72	13.4	+4.2
	August	75	71	13.2	+4.0
Hartford, Conn.	July	77	74	12.8	+3.7
	August	74	71	12.8	+3.7

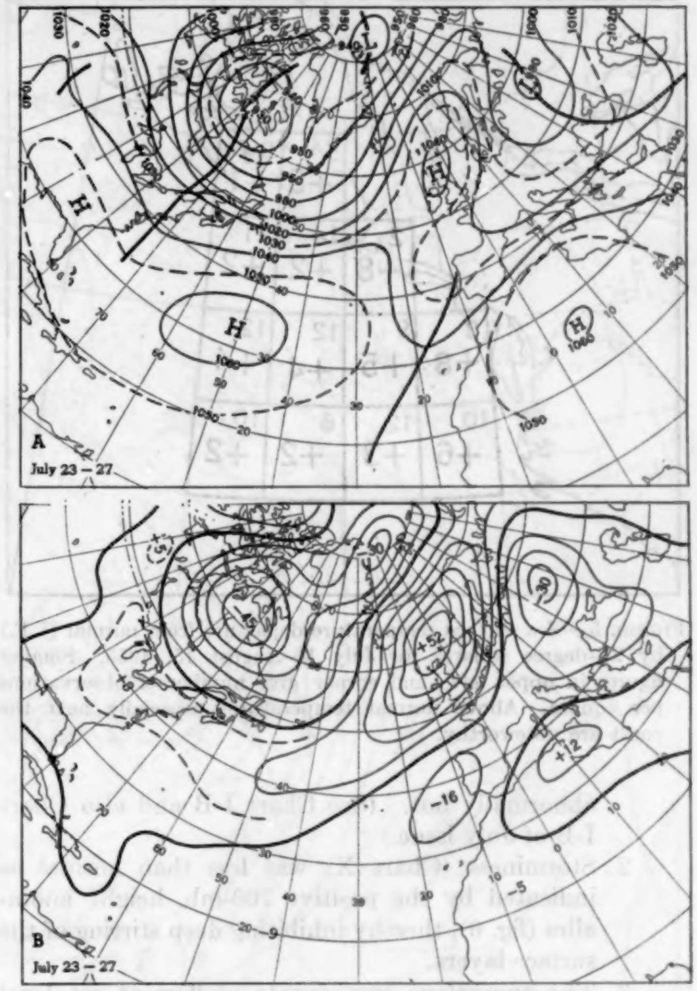

FIGURE 4.—(A) Mean 700-mb. contours and (B) mean, 700-mb. height departures from normal (both in tens of feet) for July 23–27, 1955. Sharp trough west of the Spanish and African coasts resulting from projecting ridge to its north was probable spawning ground for hurricane Connie.

In order to test this hypothesis all ship observations taken from mid-July to mid-August appearing on the eight synoptic charts per day in the area off the northeast coast were gathered and tabulated in the 2½-degree squares delineated in figure 5. The temperatures were then averaged for each square and the resultant values for the period were compared with the long-period (1912–31) averages given by Slocum [7]. The departures from this long-period average (or normal) are given in figure 5 along with the number of observations in each square. There seems to be little question that surface water temperatures off the northeast coast were above normal and especially so in areas close to the coast. While the complete explanation of this anomaly is a problem primarily for oceanographers, it appears that atmospheric conditions of July and early August favored abnormal heating of surface waters in this area because:

1. The air masses over the entire Northeast were

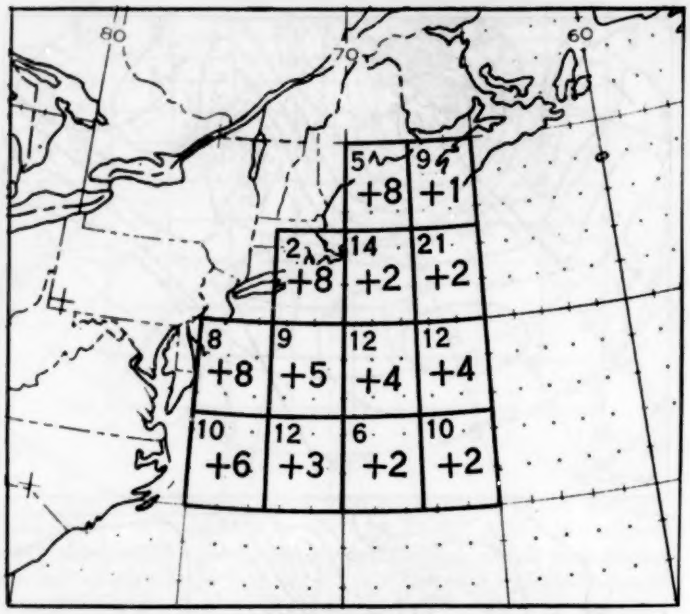

Figure 5.—Sea surface temperature departure from normal (° F.) by 2½-degree squares for July 16–August 15, 1955. Smaller figures in upper left hand corner give number of observations per square. Above normal temperatures especially near the coast are noteworthy.

abnormally hot. (See Chart I-B and also Chart I-B of July issue.)

2. Storminess (Chart X) was less than normal as indicated by the positive 700-mb. height anomalies (fig. 6), thereby inhibiting deep stirring of the surface layers.
3. The anomalous components of flow at sea level (Chart XI) suggest more than normal advective drift of warm water shoreward and weaker than normal prevailing southwesterly winds at the surface.
4. The mean pressure patterns (and absence of storms) suggest that more sunshine than normal affected the area, thus contributing to warming. Solar radiation measurements at Blue Hill Observatory, Mass., during July for example, showed an excess above normal of 13 percent in total radiation falling on a horizontal surface.

From hygrometric tables it appears that increases in mixing ratio of 4.0 g/kg as observed in July and August in southern New England would be of the general magnitude anticipated if the surface waters along the coast averaged from 5° to 10° above normal, as is indicated by figure 5.

An inspection of the synoptic charts for several days preceding hurricanes Connie and Diane indicates that air trajectories arriving over the northeast portion of the country emanated from a general southeasterly direction, thus moving across the Gulf Stream and coastal waters. Along the trajectories it appears that observed water temperatures equalled or exceeded dew point temperatures, thus making possible continual addition of moisture to the air from the sea, or at least helping to maintain the high moisture content characteristic of tropical air at its source.

The suggestion is that the torrential rains accompanying hurricanes Connie and Diane, particularly Diane which moved just south of New England, were caused not only by the usual factors associated with hurricanes, but also by the abundance of moisture supplied by an appreciably warmer than normal ocean source. Of course, this would not explain the complex detail of the isohyetal patterns of both storms. Expressed in other words, it seems that the oceanic source region for tropical air was in July and August of 1955 effectively extended northward along the Atlantic Seaboard. At least, these data are of sufficient interest to suggest that studies of ocean temperature anomalies should not be ignored in the search for the many rain-producing elements associated with tropical cyclones.

2. FORM OF THE GENERAL CIRCULATION

PRESSURE DISTRIBUTION

The pressure distribution in mid-troposphere during the month of August was very persistent and is well represented by the 700-mb. monthly mean (fig. 6). Planetary waves in the westerlies possessed little amplitude, except in Europe and western portions of the Soviet Union. The pronounced zonal nature of the mid-tropospheric flow is illustrated in figure 6 by the 700-mb. height departures from normal, where it is shown that a narrow filament of positive departures roughly along 45° N. latitude extended continuously through the troughs and ridges from China eastward to Europe. In polar regions vigorous cyclonic activity prevailed resulting in extensive below normal values of pressure at sea level (Chart XI) and height at 700 mb. (fig. 6). The 5-day 700-mb. departures from normal for periods one week apart during August (fig. 7A–D) illustrate the persistent nature of cyclonic activity in the Arctic.

Two other persistent anomalies which were apparently cornerstones of the monthly mean circulation were those over northern Europe and the west central Pacific (fig. 6). The former became established early in summer and maintained throughout the season [3 and 8]. During the period August 3–7 (fig. 7A) 5-day mean 700-mb. heights averaged above normal west of the British Isles, but by the following week (fig. 7B) this anomaly had progressed to Scandinavia where it remained throughout August. This prevalence of upper level anticyclones gave Scandinavia one of its finest tourist seasons in terms of sunny, rainless weather.

The positive monthly mean anomaly (310 feet) in the west central Pacific occupied an area normally characterized by a trough [9]. The sequence of 5-day mean height departures from normal (fig. 7) shows that a positive anomaly center in the central Pacific retrograded early in the month to a fairly settled position. The resulting

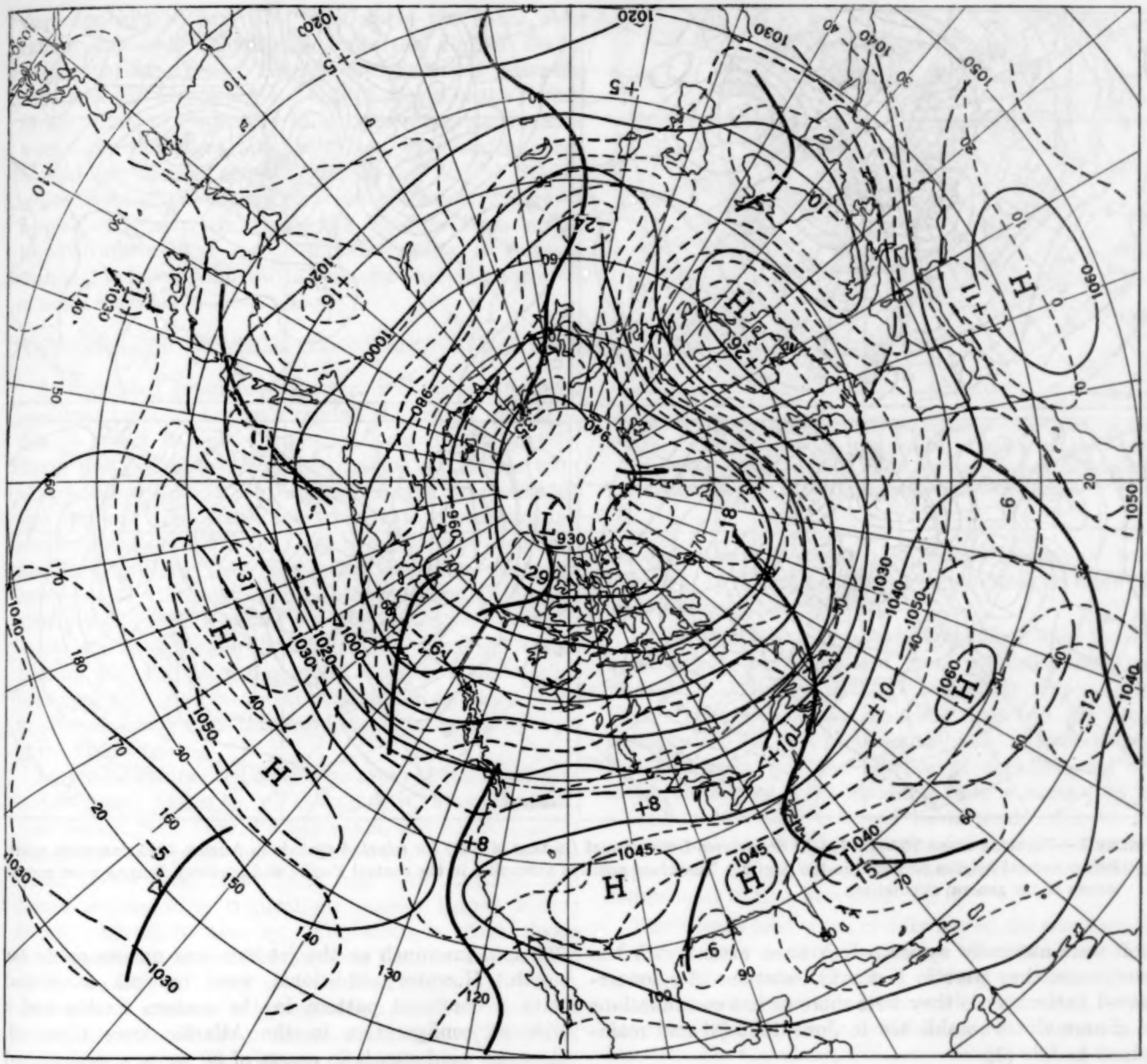

FIGURE 6.—Mean 700-mb. contours and height departure from normal (both in tens of feet) for August 1955. Note continuous zonal band of positive anomalies in middle latitude associated with contracted circumpolar vortex. Subnormal heights in tropical and western Atlantic as in July [3] appear to represent a long period "weakness" favoring formation of early season hurricanes.

westward displacement of the Pacific ridge encouraged storminess in the Gulf of Alaska, which in turn helped perpetuate a fast, zonal flow across North America.

Northward displacement of the westerlies, subtropical ridge, and intertropical convergence zone encouraged tropical disturbances to spawn frequently and early in August as described previously. Monthly mean sea level pressures (Chart XI) and 700-mb. heights (fig. 6) averaged below normal across the tropical Atlantic and southeastern United States with a maximum deficiency over the Sargasso Sea where at 700 mb. (fig. 6) a 10,400-ft. closed upper level cyclone was observed—a unique case in the historical record of 700-mb. mean maps dating from 1933. The most similar 700-mb. pattern for this immediate area occurred in August 1933 when a negative anomaly of 110 feet was observed east of Florida and the westerlies along the Atlantic Seaboard were subnormal. This case is mentioned because 1933 was a year unusually rich in tropical disturbances and included an intense hurricane which entered the mainland just north of Cape Hatteras.

While the mean negative anomalies at sea level and

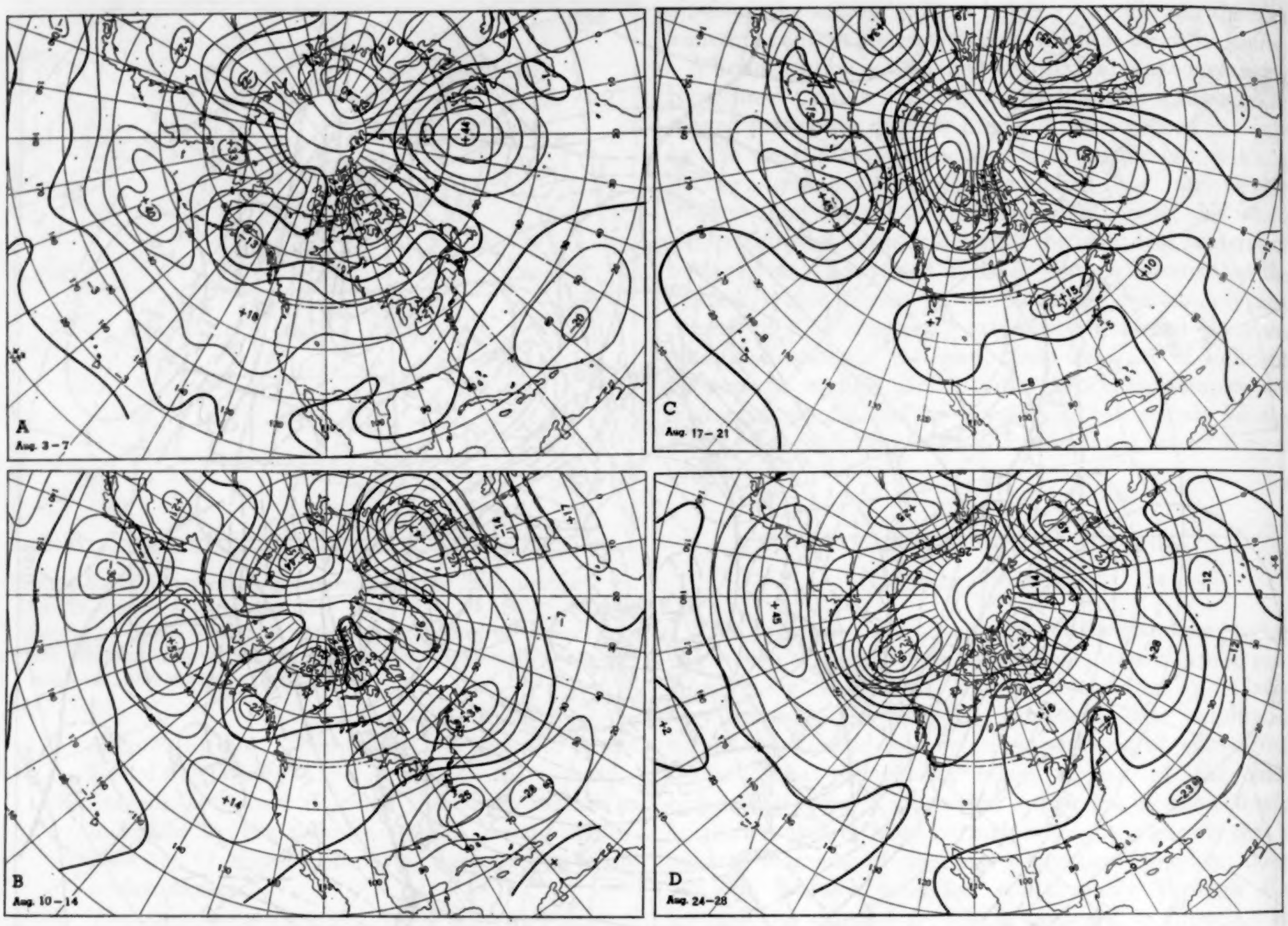

FIGURE 7.—Five-day mean 700-mb. height departures from normal (in tens of feet) for selected periods in August 1955 one week apart. Below normal heights persisted in the Arctic. Tenacious positive anomalies in the central Pacific and northern Europe were cornerstones of the general circulation.

aloft were naturally associated to some extent with the hurricanes, they were in fact manifestations of a longer-period pattern since they were more or less continuations of abnormalities established in June 1955 [8] and maintained in July [3].

ASSOCIATED WIND PATTERNS

The contracted polar vortex was associated with zonal wind speeds at 700 mb. about 5 m. p. s. greater than normal north of 45° N. latitude but below normal south of 45° N. (fig. 1). The maximum wind belt in August was approximately 5° of latitude north of normal (fig. 2A). The continuous bands of excess polar westerlies and subtropical easterlies at the expense of temperate latitude westerlies (fig. 2B) resulted in a rather uniform northward shift of the waves in the westerlies. The anomalous easterly flow in middle and low latitudes was responsible for the drift of August hurricanes onto the United States mainland, northwest of the more normal oceanic trajectory.

At 200 mb. the wind field (fig. 8) was similar to that at 700 mb. inasmuch as the jet axis was unseasonably far north. However, additional wind maxima associated with a confluent pattern in the eastern Pacific and a difluent configuration in the Atlantic were observed. Average wind speeds in excess of 30 m. p. s. maintained over parts of North America. On normal maps for the 13-km. level (about 200 mb.) the westerlies during August increase uniformly from about 5 m. p. s. in northern Florida to 20 m. p. s. in central New England [10]. In August 1955 easterlies existed at 200-mb. levels from the latitude of Florida to Cape Hatteras, and the westerlies north of Hatteras were about 5 m. p. s. below normal. Therefore, the hurricanes of this August had a high probability of encountering prevailing deep easterly currents extending from the surface to the tropopause.

CYCLONE TRACKS

Most of the extratropical cyclones of August were observed north of the axis of maximum mid-tropospheric westerlies, although no strongly preferred storm tracks

were apparent (Chart X). In Canada the paths were rather uniformly distributed from the United States border to the Arctic. Several storms passed near the Aleutians and moved into the Gulf of Alaska or the Bering Strait. East of the Rocky Mountains the cyclone tracks were more numerous but only three weak disturbances formed far enough south to affect the United States, where most of the storms entering the country were of tropical origin. Here again the freedom from extratropical storms and increased vulnerability to tropical storms is to be associated with the northward displacement of zonal wind belts.

3. PREVAILING WEATHER OVER THE UNITED STATES

As indicated previously showers and tropical storms produced most of August's rainfall (Charts II and III). With a mean 700-mb. anticyclone located over western Texas and New Mexico moist unstable air masses were advected into the Far Southwest producing heavy rainfall and floods in Arizona and lesser amounts of precipitation north-northeastward to the Canadian Border in a manner described by Reed [11]. The rather anomalous westward extension of "Arizona rains" into southern California, often called "Sonora rains," was associated with easterly winds aloft, as noted by Blake [12]. Tropical storm Brenda which entered Louisiana August 1 (for earlier history see [3]) combined with other easterly perturbations to produce heavy rains totaling up to 10 inches along most of the Gulf Coast.

Abundant rainfall fell over large areas of the Northeast and in many States (e. g., Connecticut, Massachusetts, New Jersey, New York, Pennsylvania, and Rhode Island) torrential downpours led to disastrous floods. In the Great Lakes area, New York, and New England cold fronts encountering tropical air masses helped induce strong convective activity. For example, flash floods were reported August 17 in northern Vermont and August 13 in the Upper Valley of New Hampshire. However, the heaviest amounts of precipitation occurred when this humid air entered the moisture-wringing circulations of hurricanes Connie and Diane. Attended by hurricane-force winds, Connie came inland in North Carolina on August 12 (Chart X) and in so doing released as much as 5 to 6 inches of rain along and east of its meandering path. Heavy rains in New York and New England fell on August 12 and 13 due to Connie's influence, although the storm center was still several hundred miles to the south. These rains were augmented by lifting of moist air over a cold front which passed through New England. A somewhat similar situation occurred in 1954 in Ontario when hurricane Hazel produced flood conditions [13]. Hurricane Diane with 70- to 100-m. p. h. winds followed in the wake of Connie and struck the coast near Wilmington, N. C. (Chart X). A detailed description of the hurricane trajectories is presented by Chapman and Sloan elsewhere in this issue. Coarse figures of rainfall amounts

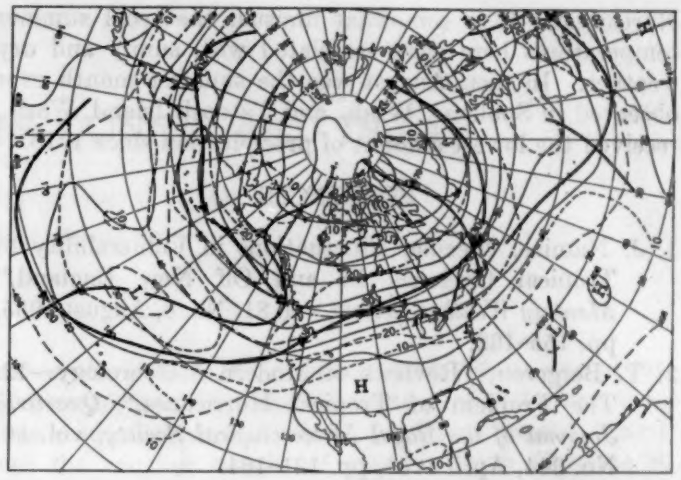

FIGURE 8.—Mean 200-mb. contours (in hundreds of feet) and isotachs (dashed, in meters per second) for August 1955. Solid arrows indicate the axes of mean jet streams, which were north of normal in eastern North America and the Atlantic.

associated with Diane varied from 6 inches in North Carolina, 11 in Virginia, 10 in Pennsylvania, to more than 20 in southern New England.

In the Far West dry weather prevailed since the west coast trough was weak and local westerlies were subnormal thereby minimizing orographic effects. The Central Plains were also dry; less than half the normal precipitation fell in a north-south band. Associated with this deficiency was the absence of cyclones and deep moist air masses, both resulting from a northward displaced and zonally oriented subtropical ridge of high pressures aloft. Rainfall was also deficient underneath an upper level anticyclone in the Southeast where northerly components of flow prevailed (fig. 6).

The intense heat wave of July across the northern half of the country east of the Rocky Mountains, continued throughout August (Chart I). Many stations reported temperatures comparable to those of August 1947, another hot month, and at some stations new records were made. For example, Cleveland, Ohio, experienced the second hottest month on record which followed the hottest month ever recorded. The mean monthly temperature at East Lansing, Mich., of 75.4° F. exceeded the old record made in 1947. Sioux City, Iowa, reported torrid temperatures, bright sunshine, hot winds, and low humidities which, combined with light precipitation, resulted in heavy crop damage. These meteorological conditions were characteristic of much of the Plains States where a crop moisture deficit [14] of 4 inches was reported throughout August.

In the Rocky Mountains and along the Gulf Coast below normal temperatures were less extensive than in July, but they still prevailed in parts of the rainy Southwest and the West Coast. August was the seventh consecutive month of subnormal temperatures in the Pacific

Northwest. It is somewhat unusual that cool summer temperatures here were associated with sunny and dry weather. In fact, August was the sunniest month ever observed in Spokane, Wash., and Tatoosh Island, Wash., received the lowest amount of precipitation since 1916.

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THE PATHS OF HURRICANES CONNIE AND DIANE

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1. INTRODUCTION

Tracks of tropical cyclones in August show that a large percentage of the storms that form in the central Atlantic east of the West Indies move on a west-northwesterly course just north of these islands and then make a shallow curve to a more northwesterly direction along or near the Atlantic Seaboard. An abrupt change in direction that usually follows a marked slowing down of the storm on its northwesterly course is often termed the point of recurvature. The direction of recurvature is usually northeasterly which takes the storm out to sea. When the storm arrives at the point of recurvature it is at the most difficult position for predicting its future direction. Storms moving inland usually begin filling rapidly and their winds decrease somewhat in intensity. However, the threat of damage from strong winds, heavy rains, and floods usually prevails along the entire path of the storm.

This article deals with two hurricanes, Connie and Diane, that crossed the North Carolina coast near the middle of August 1955 and inflicted great damage over a large area of the eastern seaboard. Connie was first detected at 0630 GMT August 4 (fig. 1) about 1,200 miles east of San Juan, P. R. and moved on an irregular course west-northwestward to northwestward just north of the West Indies. By 1230 GMT August 11, when it was southeast of the North Carolina coast, Connie began decreasing its forward motion thus indicating a strong tendency to recurve. It turned abruptly north-northeastward and crossed the North Carolina coast near Cherry Point at 1500 GMT, August 12. On crossing the coastline, Connie weakened, but remained an intense storm as it continued generally northward to near the latitude of Washington, D. C. It then turned northwestward and began filling rapidly as it crossed the higher terrain of Pennsylvania and filled further as it moved into the Great Lakes area.

Diane, the weaker of the two storms, was first detected at 0630 GMT August 11 (fig. 1) about 450 miles northeast of San Juan, P. R. and moved on an erratic course generally northward for two days. It then turned to a more stable west-northwest direction similar to Connie's path. Unlike Connie, Diane did not give any indication of recurving by slowing down its forward motion. Rather, it continued on its regular course northwestward and crossed the North Carolina coast near Wilmington about 1500 GMT August 17, some 100 miles west of the area that Connie hit five days earlier. As Diane passed inland over the rougher terrain of central North Carolina it filled rapidly and continued weakening as it turned slowly northward toward Martinsburg, W. Va., crossing the high terrain of Virginia. Near the latitude of Martinsburg, W. Va., Diane abruptly turned to the northeast with little change in intensity until it started slowly deepening after passing off the coast near Long Island. Very heavy rains occurred along the track of both storms.

In our review of these two storms we shall investigate the applicability of some of the techniques that are used

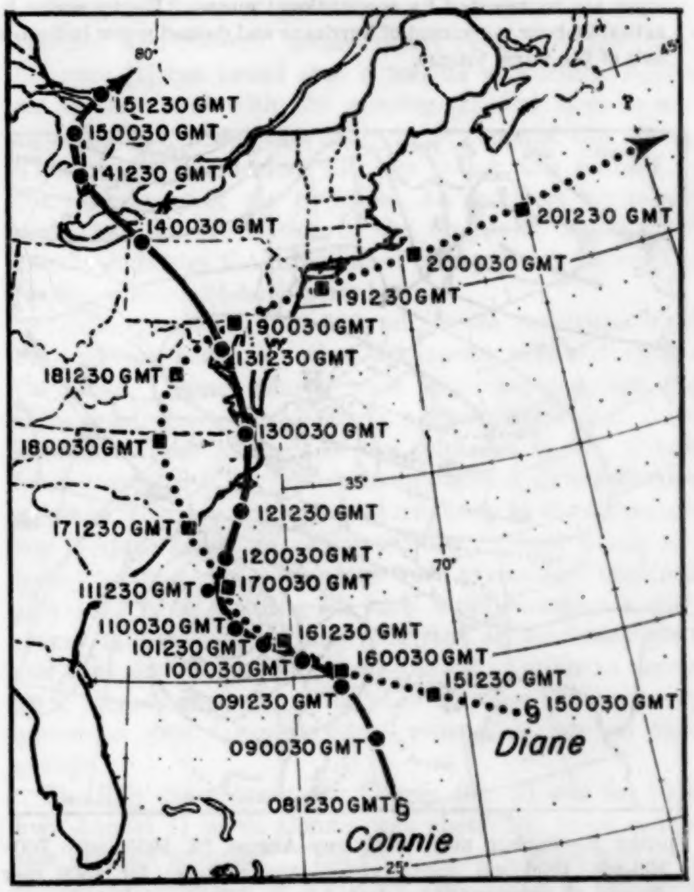


Figure 1.—Tracks of Hurricane Connie (solid line) and Hurricane Diane (dotted line) with 12-hourly positions indicated.

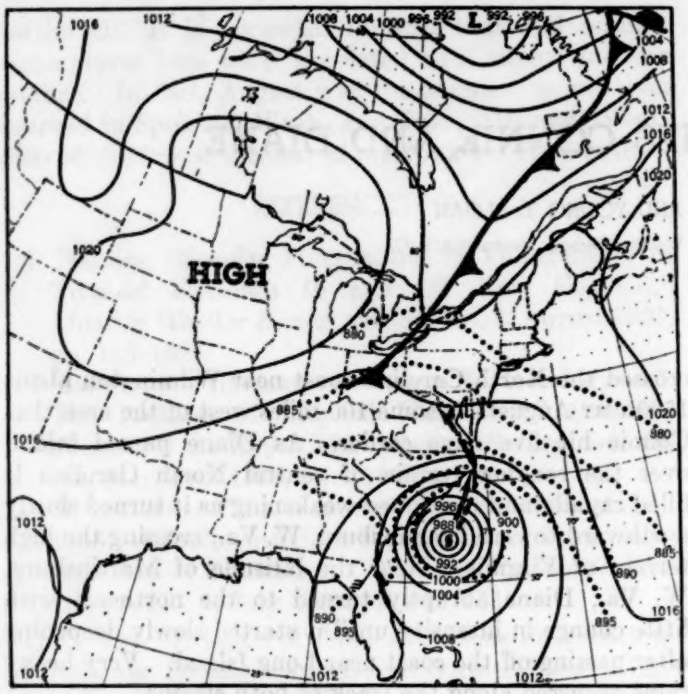


FIGURE 2.—Surface map, 1230 GMT, August 11, 1955, with 700–500-mb. thickness (mean virtual temperature) for 1500 GMT August 11 represented by dotted lines. Thermal winds for this layer are represented by conventional means. Heavy arrow is actual 24-hour movement of hurricane and dashed arrow indicates axis of the warm tongue.

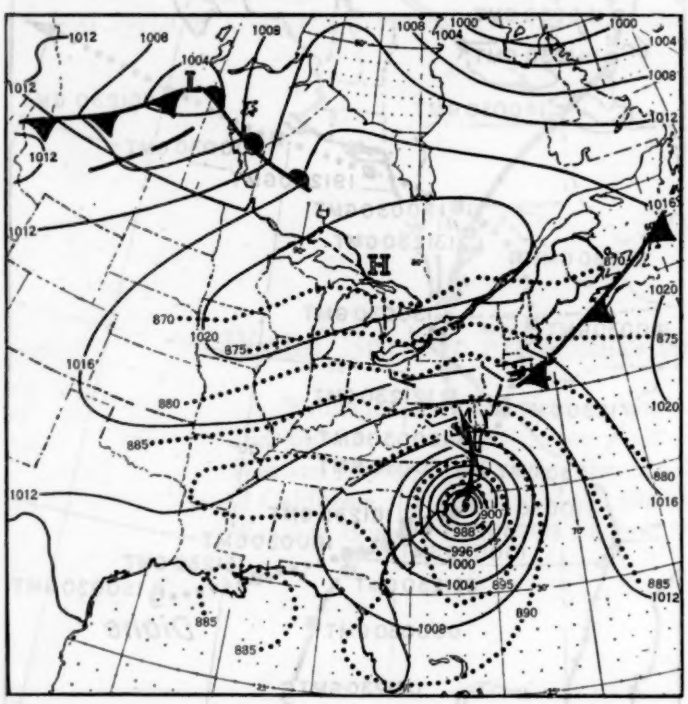


FIGURE 3.—Surface map, 1230 GMT August 12, 1955, with 700–500-mb. thickness (mean virtual temperature) for 1500 GMT August 12 represented by dotted lines. Thermal winds for this layer are represented by conventional means. Heavy arrow is actual 24-hour movement of the hurricane which in this instance coincided with the axis of the warm tongue.

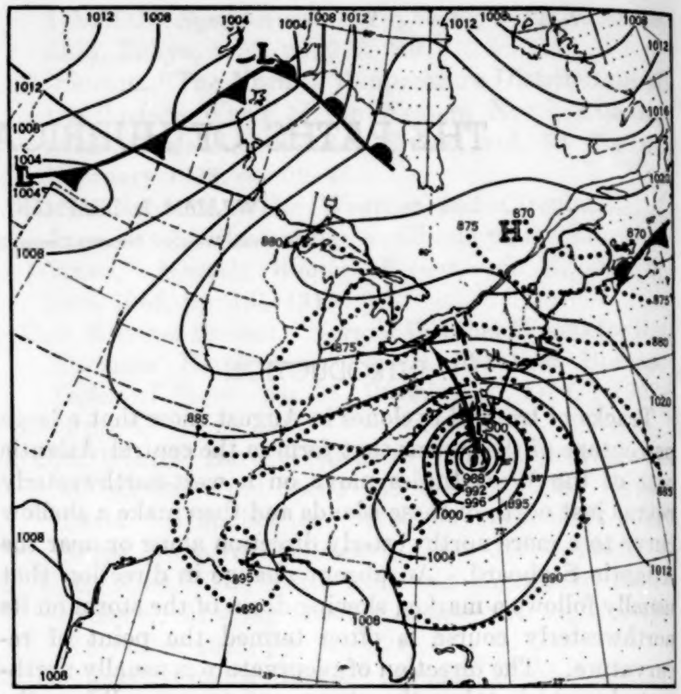


FIGURE 4.—Surface map, 0030 GMT August 13, 1955, with 700–500-mb. thickness (mean virtual temperature) for 0300 GMT August 13 represented by dotted lines. Thermal winds for this layer are represented by conventional means. Heavy arrow is actual 24-hour movement of the hurricane and dashed arrow indicates axis of the warm tongue.

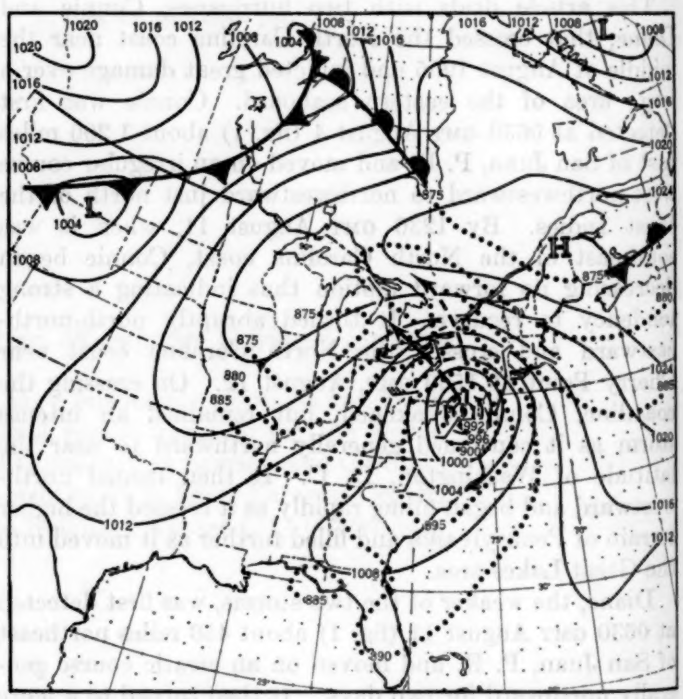


FIGURE 5.—Surface map, 1230 GMT August 13, 1955, with 700–500-mb. thickness (mean virtual temperature) for 1500 GMT August 13 represented by dotted lines. Thermal winds for this layer are represented by conventional means. Heavy arrow is actual 24-hour movement of the hurricane and dashed arrow indicates axis of the warm tongue.

at National Weather Analysis Center in predicting the 24-hour movement of hurricanes, namely Simpson's [1] warm tongue technique, Riehl and Haggard [2] computations, and high level steering.

2. SURFACE SYNOPTIC FEATURES

The dominant features of the 1230 GMT August 11 surface map (fig. 2) were: Hurricane Connie located just off the Carolina coast, a high center over the North Central States, another high center southeast of Newfoundland, and a cold front extending southwestward from eastern Canada across the eastern Lake Region. By 1230 GMT August 12 (fig. 3), Connie had recurved north-northeastward to just off Cherry Point, N. C., after first slowing to almost a halt some 12 hours earlier. As the cold front continued eastward across southeastern Canada, the High in the North Central States moved over the Great Lakes and began building eastward toward the St. Lawrence Valley. Another frontal system (fig. 4) moved into the Northwestern States with a wave developing near Lake Winnipeg. As the new frontal system moved northeast into the northwestern portion of Hudson Bay, as indicated on the 1230 GMT August 13 surface map (fig. 5), the High from the central Great Lakes moved rapidly eastward toward Maine with indications at this time for amalgamation with the High over the western Atlantic which had shown only a slow eastward motion from its position on the 11th. With this eastward shift of the High from the Great Lakes, Connie continued northward for about 12 hours and then started moving slightly west of north after passing Norfolk, Va. It was apparently coming under the influence of the strong easterly component developing to its north. During the next 24 hours Connie continued northwestward across central Pennsylvania and western New York, being steered around the blocking High to the northeast which finally amalgamated with the Atlantic cell by the end of the period. Connie continued filling in the Great Lakes region and was finally absorbed by the system from the west.

The dominant features of the surface map for 1230 GMT August 16 (fig. 6), when Diane was some 200 miles southeast of the Carolinas, were somewhat different from those just described when Connie was located off the Carolinas. A weak high center was located over eastern Pennsylvania with an east-west frontal system across the northern United States and southern Canada. This system was characterized by a weak wave over the Great Lakes and an occlusion in western Canada with a Low at the point of occlusion just north of Montana. A 1026 High was centered over Hudson Bay and another stationary High was located east of Bermuda. By the 1230 GMT August 17 map, figure 7, the waves in southern Canada had deepened a little and moved northeastward about 5° while the high center from Hudson Bay had moved rapidly southeastward to the vicinity of Nova Scotia. Meanwhile Diane continued on a slow but regular northwest path to near Wilmington, N. C. Through the 24-hour period ending at 1230 GMT, August 18 (figs. 8 and 9), the waves along the northern United States border continued eastward with the High over Nova Scotia passing east-southeastward off Newfoundland. A weak high cell began to appear in eastern Iowa as Diane continued its slow curve north-northeastward toward Martinsburg, W.Va. By the end of the period, marked deepening of the occluded system over western Hudson Bay was noted while the first wave, now north of Diane, began filling. With continued deepening over Hudson Bay the occluded front and trough were accelerated eastward during the next 24 hours as the first wave continued filling. Apparently as a result of the deepening that had taken place in the vicinity of Hudson Bay the zonal westerlies aloft increased across southern Canada with a resultant build eastward of the ridge aloft and at the surface over Iowa. This action of the westerlies was instrumental in forcing Diane to take a sharp turn eastward after passing north of Washington, D. C. It passed off the coast south of Long Island, N. Y., at 1230 GMT, August 19, as the High from Iowa moved eastward into Indiana.

3. SIMPSON'S WARM TONGUE TECHNIQUE

By using charts of the difference in height between the 700-mb. and 500-mb. levels (mean virtual temperature) Simpson [1] has found that a tongue of warmer, lighter air is associated with the moving tropical cyclone and extends from 800–1,200 miles in advance of the storm. This tongue is oriented with its major axis parallel to the movement of the cyclone. An excellent lag exists, such that the orientation of the tongue at any instant usually indicates the direction of the cyclone's movement for the ensuing 24-hour period.

Thickness charts, 700–500 mb., were constructed for both storms, beginning when the storms were well off the Carolinas. These charts were superimposed on the corresponding regular 12-hourly surface charts (figs. 2–9). To support our analysis of the thickness charts, drawn for increments of 50 feet from subtracted data (obvious errors in data were corrected by reference to the surrounding thermal field), we calculated the thermal winds adjacent to the storm when data were available. One will note that when drawing for such small increments with sparse data it is highly desirable that all stations report and that the reports be quite accurate in order to arrive at a correct analysis. This also stresses the need for numerous RAWIN reports since PIBALS do not go high enough.

The first chart drawn for Connie (fig. 2) was for 1500 GMT August 11 when Connie was about 100 miles southeast of the Carolinas. This position for Connie was very critical prognostic-wise since we had noted a tendency for recurvature from surface indications. No wind reports were received from Charleston, S. C., or Cape

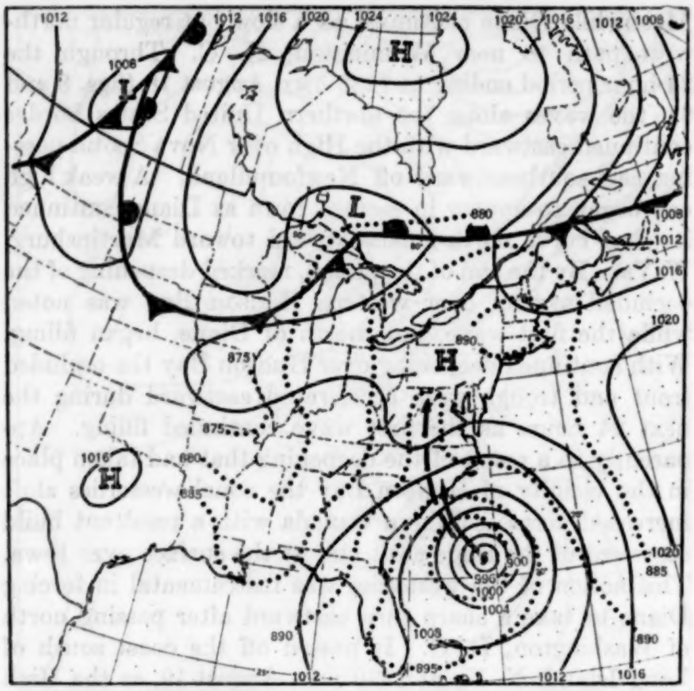


FIGURE 6.—Surface map, 1230 GMT August 16, 1955, with 700–500-mb. thickness (mean virtual temperature) for 1500 GMT August 16 represented by dotted lines. Thermal winds for this layer are represented by conventional means. Heavy arrow is actual 24-hour movement of the hurricane and dashed arrow indicates axis of the warm tongue.

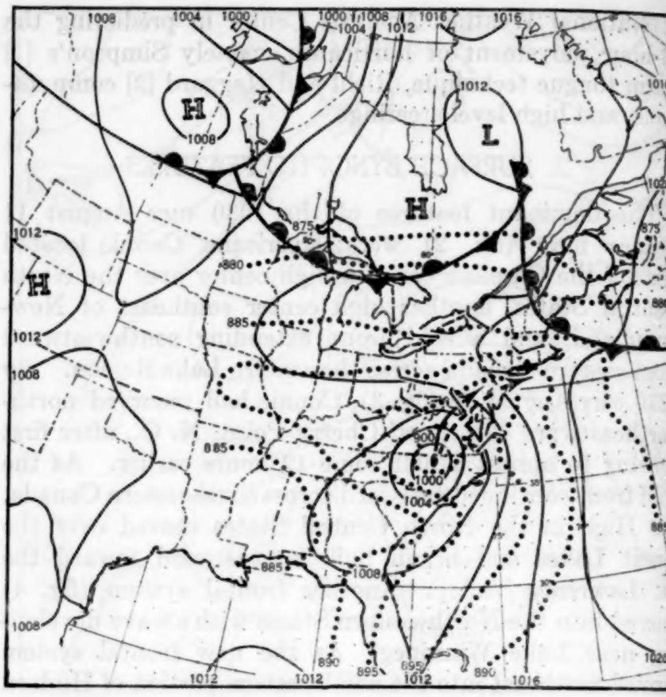


FIGURE 8.—Surface map, 0030 GMT August 18, 1955, with 700–500-mb. thickness (mean virtual temperature) for 0300 GMT August 18 represented by dotted lines. Thermal winds for this layer are represented by conventional means. Heavy arrow is actual 24-hour movement of the hurricane and dashed arrow indicates axis of the warm tongue.

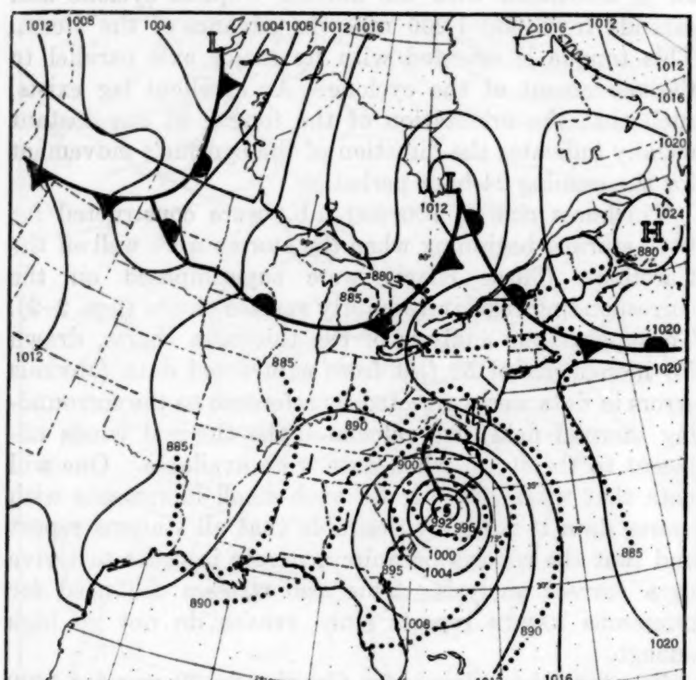


FIGURE 7.—Surface map, 1230 GMT August 17, 1955, with 700–500-mb. thickness (mean virtual temperature) for 1500 GMT August 17 represented by dotted lines. Thermal winds for this layer are represented by conventional means. Heavy arrow is actual 24-hour movement of the hurricane which in this instance coincided with the axis of the warm tongue.

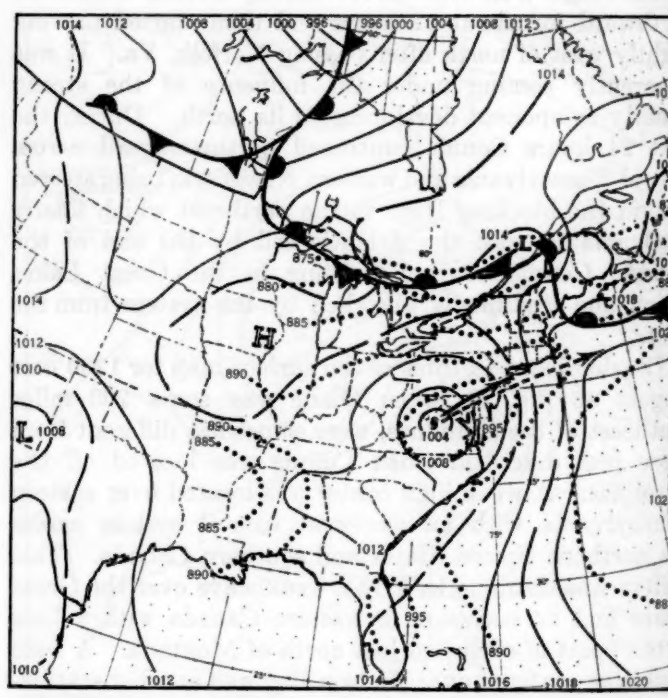


FIGURE 9.—Surface map, 1230 GMT August 18, 1955, with 700–500-mb. thickness (mean virtual temperature) for 1500 GMT August 18 represented by dotted lines. Thermal winds for this layer are represented by conventional means. Heavy arrow is actual 24-hour movement of the hurricane and dashed arrow is axis of the warm tongue.

Hatteras, N. C., so we had no nearby thermal wind computations to support our thickness analysis. The position of the axis of the warm tongue, shown toward the north-northeast instead of west-northwest, was based on the continuity of the warm tongue axis for the previous 24 hours which indicated a marked trend toward increasing to the north while the residual tongue northwestward was weakening. With sparse or doubtful data one can see how the technique becomes quite subjective.[1]

The next chart constructed was for 1500 GMT August 12, after Connie had curved north-northeastward and was approaching the eastern tip of North Carolina (fig. 3). Supported by thermal winds, the axis of the warm tongue is indicated northward just west of Norfolk and east of Washington which coincides with the movement of Connie. The charts for 0300 and 1500 GMT August 13 (figs. 4 and 5), supported fairly well by thermal winds, indicate an axis a little west of north through eastern Pennsylvania and central New York. The actual path of the storm through the above period made an angle of 20°–30° toward the west from the warm tongue axis. This small deviation is believed to be due to the blocking effect of the High to the north of Connie as suggested earlier in the discussion of surface features and will be discussed in more detail later.

For Diane, the first chart constructed was for 1500 GMT August 16 (fig. 6), when the storm was located some 200 miles southeast of the Carolinas. As Diane did not show any marked tendency to slow its forward motion on approaching the coast, continuity considerations called for the axis of the warm tongue to lie northwestward across southern North Carolina and the actual path of Diane was along this axis. The thickness chart for 1500 GMT August 17 (fig. 7) indicates a continued northwest axis of the warm tongue through North Carolina followed by a curve northward through western Virginia. The path of Diane again coincided with this axis. The first hint of Diane's recurving sharply toward the northeast is shown in figures 8 and 9 when the warm tongue, supported by thermal winds, showed an axis northeastward along a line south of Hempstead, N. Y., and Nantucket, Mass. Diane's path throughout its course along the Atlantic Seaboard followed closely the warm tongue axis described by Simpson.

4. RIEHL AND HAGGARD COMPUTATIONS

Riehl [3] states that tropical storms move with a direction and speed closely approximating that of the tropospheric current surrounding them. If the flow at 500 mb., or some parameter based on this flow, can be taken as the tropospheric current then the storm's velocity can be determined from these charts. Further, if the computations are not made too close to the storm center, the forces which will act on the storm during the next 24 hours might be included.

[1] During a conversation with Mr. Simpson on this phase of the storm and its apparent ill-defined warm tongue, he stated he had noted a similar effect with Carol last year and feels that this lack of a well-defined warm tongue can be explained by the fact that both storms had a very slow forward speed at the time. He said theoretical considerations show that the development of the warm tongue is directly related to the progressive forward motion of the storm.

Table 1.—*Comparison of actual 24-hour movement of Connie and Diane with prognosticated movement computed by the Riehl and Haggard method*

Time of 500-mb. chart		Computed 24-hour movement		Actual movement	
		CONNIE			
GMT	*August 1955*				
1500	11	2.0° N.	0.8° E.	2.8° N.	0.5° E.
1500	12	3.8° N.	2.1° E.	5.2° N.	1.0° W.
0300	13	4.9° N.	0.8° E.	5.5° N.	3.2° W.
1500	13	5.5° N.	1.8° W.	4.0° N.	5.4° W.
		DIANE			
1500	16	2.5° N.	2.8° W.	3.5° N.	2.2° W.
1500	17	5.0° N.	1.0° E.	4.0° N.	0.2° E.
0300	18	5.0° N.	4.2° E.	3.3° N.	4.0° E.
1500	18	2.8° N.	5.2° E.	2.2° N.	5.5° E.

Following the technique outlined by Riehl and Haggard [2] and using the 500-mb. charts of NWAC (reanalyzed carefully for computed data or late data when needed), table 1 was prepared giving computations of the N-S and E-W components of the movement of Connie and Diane as compared to the actual movement. The computations were made for the same times as those for Simpson's technique and follow the surface positions of the two storms (figs. 2–9). This technique foretold accurately Connie's recurvature toward the eastern tip of North Carolina and its continued northward movement. However, it failed to catch the westward movement of Connie after passing Norfolk, Va. This deviation, we feel, is due to the fairly rapid change in the 500-mb. pattern after that time. In figure 10A is shown the advection chart that is used often at NWAC as a qualitative tool in making our 500-mb. prognostic charts. In the chart the 1000–500-mb. thickness lines are superimposed on the 1000-mb. contours for 1500 GMT August 12. Note the strong warm advection indicated toward Hudson Bay as cooler air holds over the Great Lakes. This pattern suggests that height rises will develop aloft in the eastern Hudson Bay and St. James Bay area. Figure 10B, the 500-mb. 12-hour height change chart for 0300 GMT August 13, verifies such height rises. Figure 10C shows the advection chart for 0300 GMT August 13, the second half of the forecast period during which the computations for Connie broke down. Again note the field of warm advection proceeding eastward across eastern Canada. Also at this time the warm advection with the tropical cyclone became quite noticeable over the New England States. The overall change in heights for 24 hours in eastern Canada is shown (fig. 10D) to be more than +400 feet. This height rise was effective in developing the block to the north of Connie and increasing the east-to-west component north of the storm thus steering it westward. When using the Riehl and Haggard technique it is necessary to determine

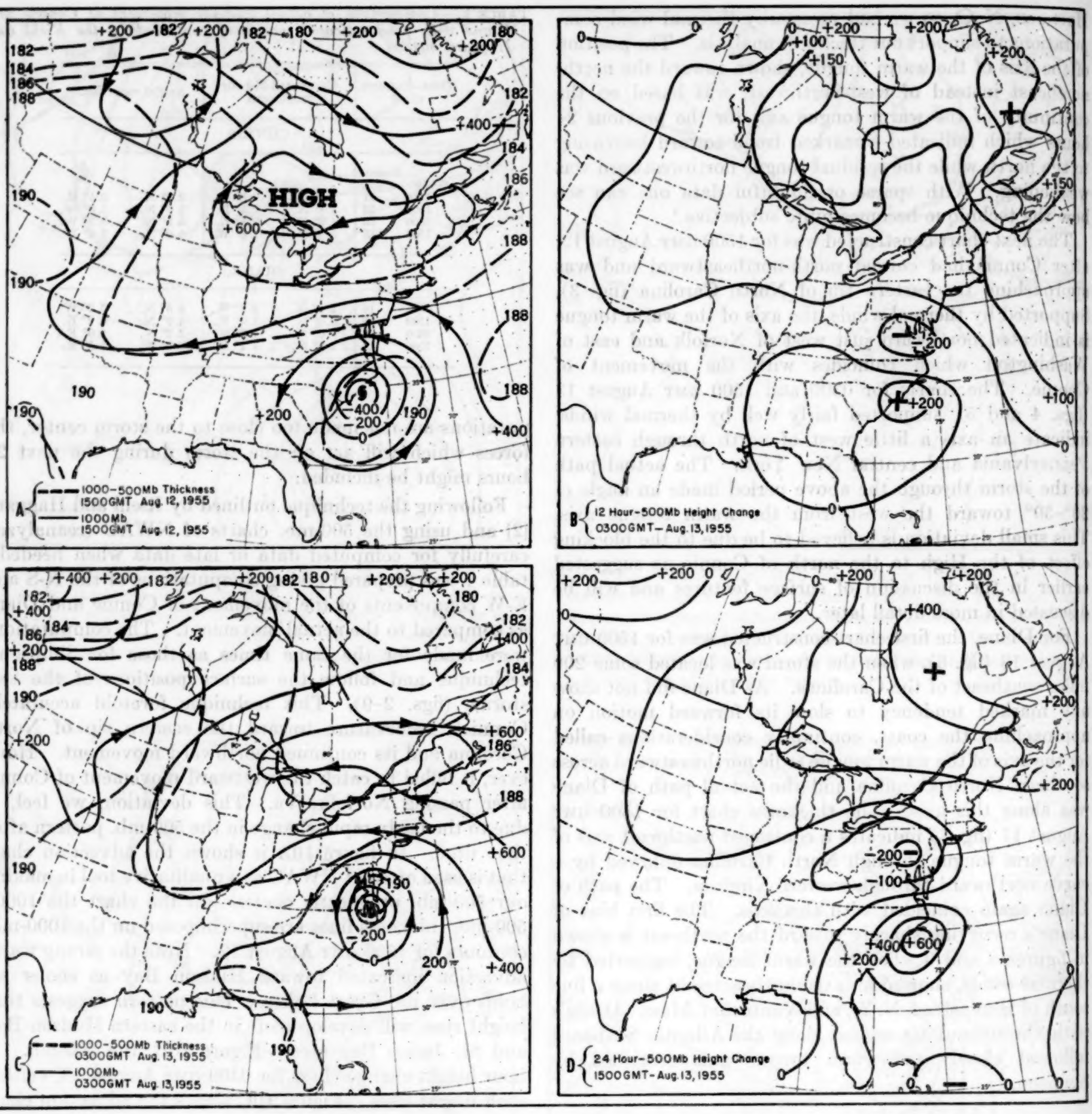


FIGURE 10.—(A) Isopleths of current 1000–500-mb. thickness (dashed) superimposed on the 1000-mb. contours (solid) for 1500 GMT August 12, 1955; (B) the 500-mb. height change in the 12-hour period following map A; (C) the current 1000–500-mb. thickness (dashed) superimposed on the 1000-mb. contours for 0300 GMT August 13, 1955; (D) the 500-mb. height change in the 24-hour period following map A.

beforehand any marked changes in the 500-mb. pattern that may occur within the forecast period for which allowances have to be made.

For Diane (fig. 11 A–D) the advection and height change charts do not indicate any large scale changes in the 500-mb. pattern adjacent to the storm through the period August 17–18. However, the area of widespread deepening over northern Hudson Bay was instrumental in speeding up the zonal westerlies across southern Canada. Correspondingly the ridge over the Central States built eastward and followed a minor trough across the New England States. This building of the ridge west of Diane was effective in curving the storm path more sharply to the east. It may be noted in table 1 that less north com-

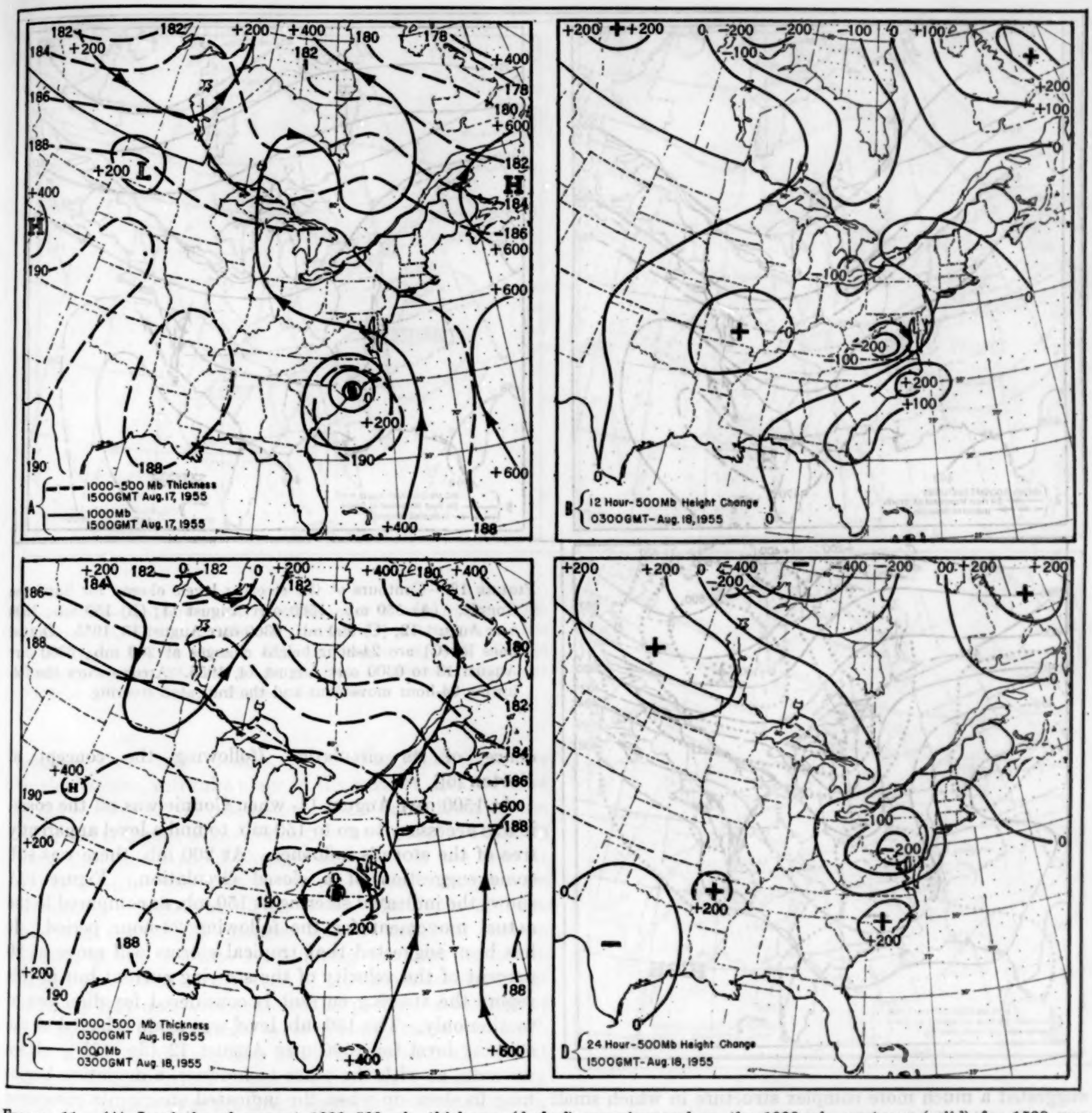


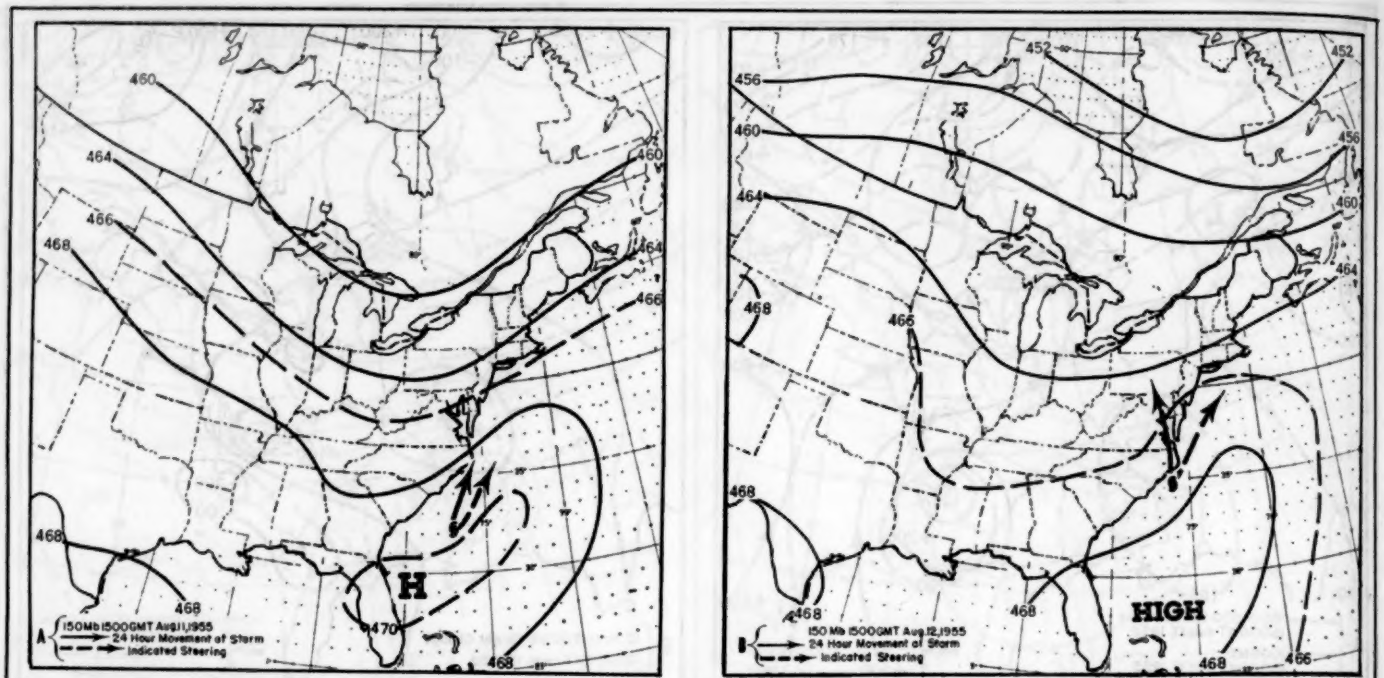
FIGURE 11.—(A) Isopleths of current 1000–500-mb. thickness (dashed) superimposed on the 1000-mb. contours (solid) for 1500 GMT August 17, 1955; (B) the 500-mb. height change in the 12-hour period following map A; (C) the current 1000–500-mb. thickness superimposed on the 100-mb. contours for 0300 GMT August 18, 1955; (D) the 500-mb. height change in the 24-hour period following map A.

ponent occurred than was forecast. The Riehl and Haggard technique gave good results for the movement of Diane.

5. HIGH LEVEL STEERING

In the earlier studies of tropical meteorology such authorities as Bowie and Weightman [4] and Mitchell [5] emphasized the steering of tropical storms by the current within which they were embedded. Often the 3-km. level was thought to be a good steering level. With the advent of higher and more numerous upper air reports, Norton [c. f. 6], Simpson [1], Dunn [7, 8], and others have found it necessary to go to very high levels in the troposphere to obtain a steering level free of the influence of well-developed tropical storms.

The actual existence of a so-called steering level has not been fully accepted. Recent studies by Simpson [9] have



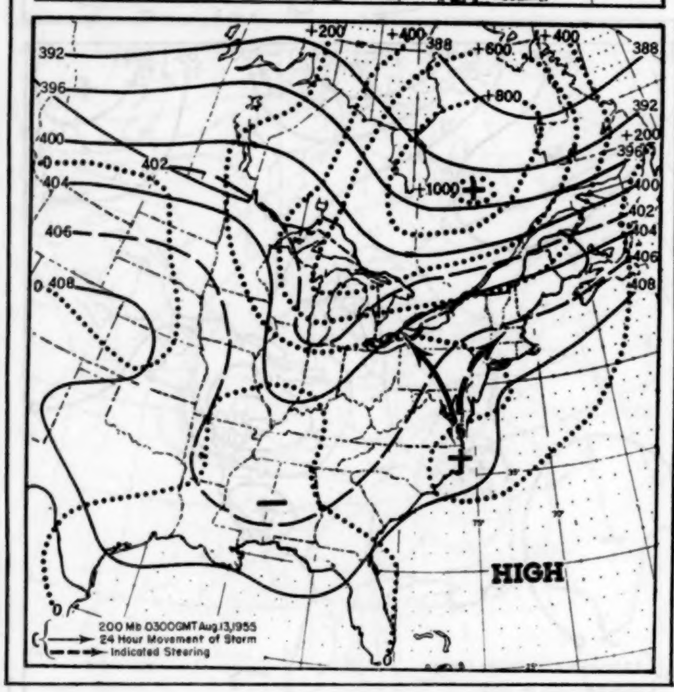


FIGURE 12.—Contours at the steering levels chosen for hurricane Connie. (A) 150 mb., 1500 GMT August 11; (B) 150 mb., 1500 GMT August 12; (C) 200 mb., 0300 GMT August 13, 1955. Dotted lines in (C) are 24-hour height changes at 200 mb., 0300 GMT August 13 to 0300 GMT August 14, 1955. Arrows show the following 24-hour movement and the indicated steering.

suggested a much more complex structure in which small cellular anticyclonic eddies form outward at higher levels from the storm's center. However, on the basis of usage by numerous forecasters, it is of interest to investigate the relation between the future movement of the storm after it has passed into mid-latitudes and the smooth flow at some higher unaffected level above the storm. The simplicity of this technique is obvious, with results obtained from a direct inspection of higher level charts where emphasis has been placed on reliable wind data. Thus, for our purposes the steering level is considered as simply the first level above the storm where there exists no evidence of its circulation (following the concept of Norton [6]).

At 1500 GMT August 11, when Connie was off the coast, it was necessary to go to 150 mb. to find a level apparently free of the storm's influence. At 200 mb. there was still some suggestion of a closed circulation. Figure 12A shows the indicated steering at 150 mb. as compared to the actual movement for the following 24-hour period. It has been suggested that tropical storms will move at 80 percent of the velocity of the steering current but in this report the steering current is considered for direction of motion only. The 150-mb. level was again selected as the steering level for 1500 GMT August 12 (fig. 12B). Here we note, as with the other techniques, a deviation beginning to show up when the indicated steering is compared to the actual movement. The upper level steering suggested a continued northeast track whereas the storm was beginning to turn north and just west of north. At 0300 GMT August 13, as the storm had filled some aloft, the 200-mb. level could be selected for steering (fig. 12C). For the first part of the period a northerly path was indicated with a turn later to the northeast through eastern Pennsylvania. However, from this time the storm continued west of north and northwestward across Pennsylvania. This deviation was to be expected since steering by the current in which the storm is embedded

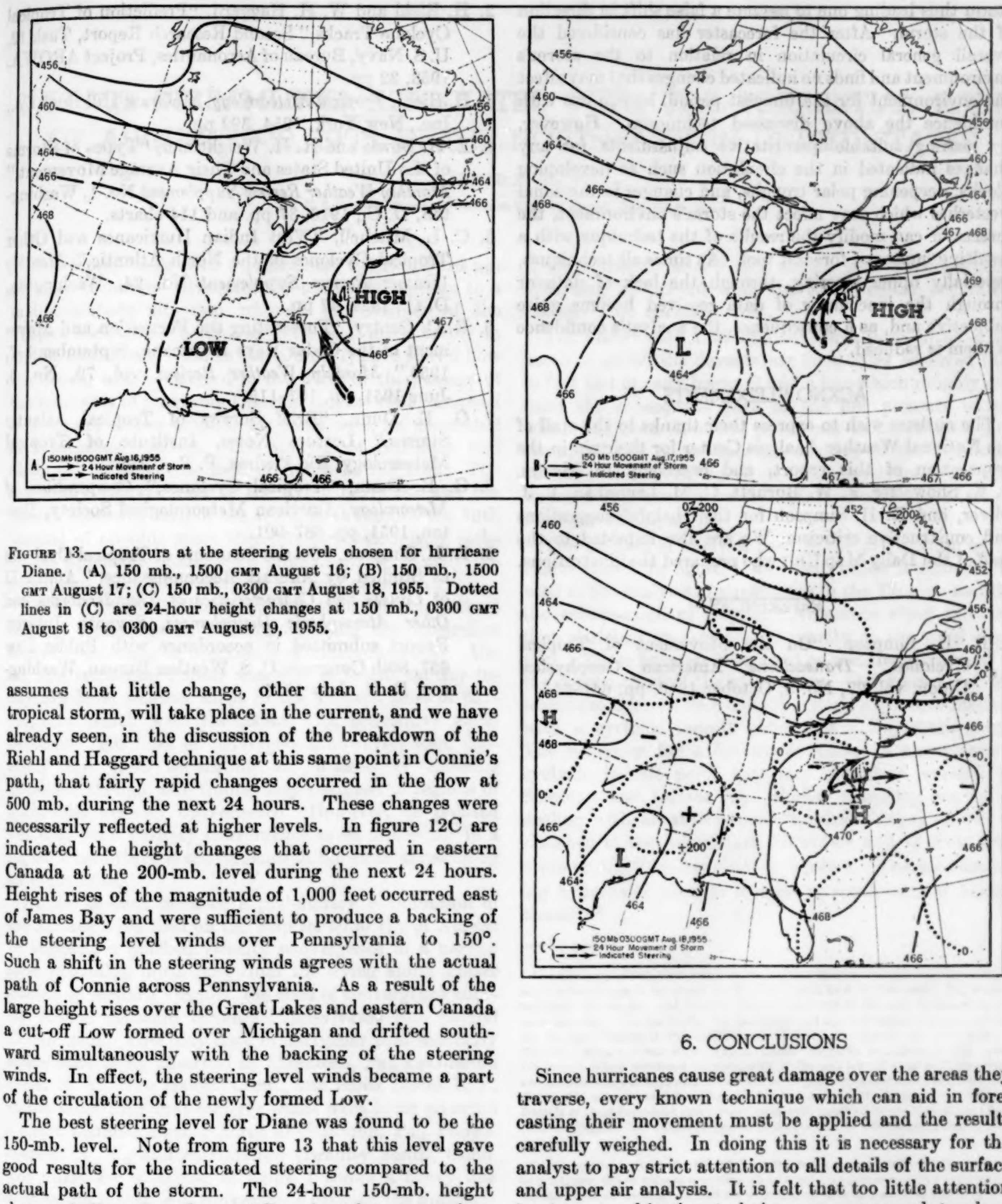


Figure 13.—Contours at the steering levels chosen for hurricane Diane. (A) 150 mb., 1500 GMT August 16; (B) 150 mb., 1500 GMT August 17; (C) 150 mb., 0300 GMT August 18, 1955. Dotted lines in (C) are 24-hour height changes at 150 mb., 0300 GMT August 18 to 0300 GMT August 19, 1955.

assumes that little change, other than that from the tropical storm, will take place in the current, and we have already seen, in the discussion of the breakdown of the Riehl and Haggard technique at this same point in Connie's path, that fairly rapid changes occurred in the flow at 500 mb. during the next 24 hours. These changes were necessarily reflected at higher levels. In figure 12C are indicated the height changes that occurred in eastern Canada at the 200-mb. level during the next 24 hours. Height rises of the magnitude of 1,000 feet occurred east of James Bay and were sufficient to produce a backing of the steering level winds over Pennsylvania to 150°. Such a shift in the steering winds agrees with the actual path of Connie across Pennsylvania. As a result of the large height rises over the Great Lakes and eastern Canada a cut-off Low formed over Michigan and drifted southward simultaneously with the backing of the steering winds. In effect, the steering level winds became a part of the circulation of the newly formed Low.

The best steering level for Diane was found to be the 150-mb. level. Note from figure 13 that this level gave good results for the indicated steering compared to the actual path of the storm. The 24-hour 150-mb. height changes indicated on figure 13C as dotted contours show only small-scale changes for the period 0300 GMT August 18 to 0300 GMT August 19.

6. CONCLUSIONS

Since hurricanes cause great damage over the areas they traverse, every known technique which can aid in forecasting their movement must be applied and the results carefully weighed. In doing this it is necessary for the analyst to pay strict attention to all details of the surface and upper air analysis. It is felt that too little attention is given to objective techniques as compared to short range forecast aspects such as following hourly positions of the storm's eye, which may be oscillating within the

storm thus leading one to assume a false shift in direction of the storm. After the forecaster has considered the overall general circulation in relation to the storm's environment and finds no indicated changes that may affect the environment for the forecast period, he can use with confidence the above discussed techniques. However, by making suitable quantitative adjustments for any changes indicated in the circulation such as developing blocks, deepening polar troughs, and changes in the zonal westerlies which may affect the storm's environment, the forecaster can modify the results of the technique with a resulting improved forecast tool. At times all techniques, especially upper steering, through the lack of data or through the inaccuracy of data received become quite subjective and, as a consequence, the analyst's confidence in them is reduced.

ACKNOWLEDGMENTS

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SURFACE STREAMLINES ASSOCIATED WITH THE TORRENTIAL RAINS OF AUGUST 18-19, 1955, IN THE NORTHEASTERN UNITED STATES

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This report deals with a preliminary effort toward applying a technique advocated for use in the Tropics to a middle-latitude situation wherein the weather of the Tropics seemed for a time to have been lifted bodily to middle latitudes. Namias and Dunn [1] have shown how the floods, which occurred in the wake of the passage of the remnants of hurricane Diane in August 1955, occurred in a homogeneous tropical air mass with its associated high moisture content. The analysis of Chapman and Sloan [2] indicates the lack of fronts in the area. The temporary rejuvenation of the dying hurricane and the sudden eastward turn of the storm as it reached the 40th parallel of latitude must therefore be studied using techniques applicable under such circumstances, namely the techniques used successfully in tropical meteorology.

C. E. Palmer [3] has proposed that the analysis of tropical situations be undertaken using the streamline analysis technique of Bjerknes and collaborators [4]. Using this technique Palmer was able to locate, on day-to-day low-level weather maps in the Tropics, lines of convergence which were associated with convective cloud patterns. His lines of convergence, however, were definitely not lines separating air masses of differing densities, though, like fronts, they occurred in regions of horizontal velocity convergence. However, he pointed out that such velocity convergence must also occur in a region where there is convergence in the streamlines along an asymptote.

In the present instance a preliminary examination of the surface wind field on the map for 0730 EST of August 18 suggests a marked velocity convergence in a narrow zone extending northward from the dying storm center located in western Virginia, the zone of convergence curving thence eastward through Pennsylvania into central Connecticut. One may note in particular that southerly winds were being observed at Allentown, Pa., LaGuardia Field, N. Y., New Haven, Conn., and Block Island, R. I., at the same time that easterly winds were being reported a short distance farther north at Scranton, Pa., Poughkeepsie, N. Y., and at Hartford (Bradley Field), Conn. The chart for 0730 EST in figure 1 shows a heavy line delineating this zone of convergence between the southerly and easterly winds. The heavy line is extended westward to show how it joins with a similar zone of convergence extending northward from the storm center separating easterly from northerly flow.

The observation that this zone was later to be a line north of which the devastating flood rains occurred (and in fact had already begun [1]) and a line which roughly outlined the subsequent path of the low pressure center, which had been identified previously as hurricane Diane, prompted this more thorough analysis of the streamline patterns shown in figure 1. The analyses were constructed at 6-hour intervals beginning with the chart for 0730 EST of August 18.

The method of analysis used in the preparation of the charts shown in figure 1 was that which is customarily used in the analysis of streamlines in the Tropics; namely, the construction of isogons. Numerous short lines are then sketched on each isogon parallel to the wind direction. These lines are then used as additional "winds" in the construction of the streamlines. An example of this technique is given by Riehl [5]. Riehl's example includes both a cyclonic indraft point and a hyperbolic point. The necessity for a hyperbolic point to accompany a cyclonic indraft point has been described recently by Sherman and LaSeur [6]. Similar reasoning applies in dealing with an anticyclonic "outdraft" wind system as sketched in the Adirondack Mountain area of New York State on the 0730 EST chart in figure 1. The accompanying hyperbolic point is located in south central Massachusetts.[2]

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[1] At the time of this chart some of the heaviest hourly amounts were occurring in areas subsequently to be struck by the flood rains, such as Honesdale, Pa., situated northeast of Scranton, and Norfolk, Conn., both within the two dominant rainfall areas associated with the floods. At Honesdale 0.72 and 1.08 inches of rainfall fell during the hours ending at 0700 and 0800 EST, respectively. During the hour ending at 0700 EST, 0.80 inch of rain fell at Norfolk, Conn. However, in addition to this, a rainfall pattern which developed independently of the two rainfall areas of Pennsylvania and Connecticut was beginning in the Boston, Mass., area where heavy rain was occurring at 0730 EST. There 0.95 inch of rain fell during the hour which ended at 0800 EST. Outside of these immediate areas, heavy rains were occurring in the Blue Ridge Mountains of Virginia, but otherwise hourly rainfall amounts were of considerably lesser magnitude.

[2] Although the location of a hyperbolic point that was associated with Diane cannot be firmly established without extending the analysis to a larger area, such a point may be the one found on the chart for 1330 EST over eastern Lake Ontario as shown in figure 1. It is not shown on the chart for 0730 EST but it is probable that it existed along a northwestward extension of the asymptote of divergence located over Lake Ontario.

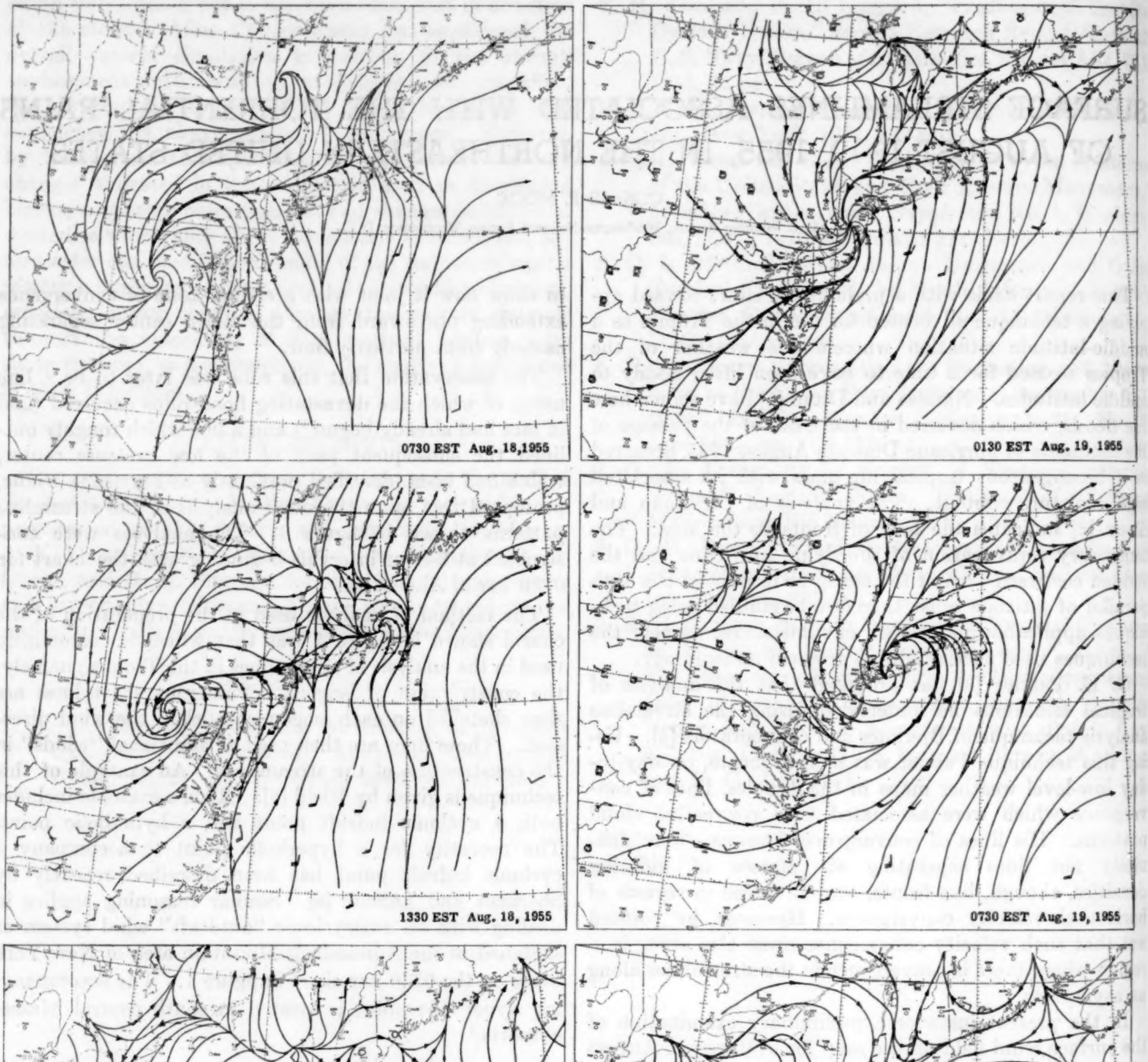

Figure 1.—Surface streamlines at 6-hour intervals, August 18–19, 1955.

The 1330 EST chart in figure 1 shows that for a brief period a cyclonic circulation developed in the Boston area, it too being accompanied by the development of a new hyperbolic point. This cyclonic indraft was associated with a second peak of hourly precipitation amounts in the Boston area which culminated in the measurement of 1.20 inches of rain there in the hour ending at 1500 EST on the 18th. This precipitation cannot be attributed to topographic lifting and must therefore be associated with a general vertical motion pattern and upper-level divergence which could have influenced the behavior of the over-all storm circulation, including the turning of the storm Diane toward the east as it reached the 40th parallel.

A third peak of precipitation occurred in the Boston area between 0700 and 1100 EST of the 19th as the storm moved eastward to the south of New England.

The occurrence of the heavier amounts of precipitation north of the line of convergence in northeastern Pennsylvania and southwestern New England can be attributed for the most part to orographic lifting of the lowest 5,000 feet of air, the air being saturated with dew points in the 70's [7]. In this connection it should, however, be noted that the orographic effect was *augmenting* a more general vertical motion and precipitation pattern which developed in advance of the storm center and that this more general vertical motion pattern produced 2 to 3 inches of rain at sea-level installations along the coast south and east of the region of topographic lifting. In the lowest 5,000 feet there was considerable horizontal *velocity* convergence in the heavy rain area which is not shown on these streamline charts in which wind speed is not a factor.

In figure 1 the primary lines of convergence are shaded more heavily than ordinary streamlines. Note especially the converging streamlines on the 1930 EST chart for August 18 in the region extending from northeastern Pennsylvania into southern New England and the general tendency for the old hurricane to bring this convergence line into its spiraling circulation in the manner suggested by Wexler [8] as the mechanism which accounts for the spiral-banded structure of hurricanes generally.

The late Dr. Isaac M. Cline [9] noted in his investigations of rainfall associated with tropical hurricanes that the temperature in the different parts of the storms which he studied did not vary greatly. He stated that the causes of the heavy rains in tropical cyclones could not be found in the surface temperature distribution (See page 220 of [9]). Finally, he noted that the region of greatest precipitation intensity was located "50 to 100 miles in front of the region where the winds of the right rear quadrant converge with those of the right front quadrant" and attributed the rainfall to the vertical motion above the zone of convergence.

Briefly summarizing, the streamline patterns shown in figure 1 reveal a marked zone of convergence which lay close to the subsequent path of the storm center and across the region of flood-producing rainfall.

Note added in proof.—A paper by Y. Masuda, M. Takeuchi, and M. Hashimoto ("On the Forecasting of the Movement of Typhoon", *Papers in Meteorology*, Meteorological Research Institute, Tokyo, vol. 3, No. 4, 1953, pp. 246–251) has just come to the attention of the author. In the 1953 paper it was suggested that typhoons move toward a point in the streamlines that corresponds to Scherhag's "delta". If on the maps for 0730 and 1330 EST, August 18 (fig. 1) this point is considered to lie in southeastern New England, the subsequent movement of hurricane Diane provides an interesting confirmation of this hypothesis.—*C.P.M.*

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3. C. E. Palmer, "Tropical Meteorology," *Compendium of Meteorology*, American Meteorological Society, Boston, 1951, pp. 859–880.
4. V. Bjerknes and collaborators, *Dynamic Meteorology and Hydrography, Part II, Kinematics*, Carnegie Institution of Washington, Publication No. 88, Part II, 1911.
5. H. Riehl, *Tropical Meteorology*, McGraw-Hill Book Company, Inc., New York, Toronto, and London, 1954, 392 pp.
6. L. Sherman and N. E. LaSeur, "Reconnaissance of the 'Complete Hurricane'," *Bulletin of the American Meteorological Society*, vol. 36, No. 4, April 1955, pp. 152–158.
7. U. S. Weather Bureau, "Hurricane Rains and Floods of August 1955, Carolinas to New England, Part 1—Meteorological Analysis," *Technical Paper* No. 26. (In preparation.)
8. H. Wexler, "Structure of Hurricanes as Determined by Radar," *Annals of the New York Academy of Sciences*, vol. XLVIII, Art. 8, September 1947, pp. 821–824.
9. I. M. Cline, *Tropical Cyclones*, The Macmillan Company, New York, 1926, 301 pp.

Suggestions for Authors

Articles are accepted for the Monthly Weather Review with the understanding that they have not been published or accepted for publication elsewhere.

Two copies of the *manuscript* should be submitted. All copy, including footnotes, references, tables, and legends for figures should be double spaced with margins of at least 1 inch on sides, top, and bottom. Some inked corrections are acceptable but pages with major changes should be retyped. The style of capitalization, abbreviation, etc., used in the Review is governed by the rules set down in the Government Printing Office Style Manual.

Tables should be typed each on a separate page, with a title provided. They should be numbered consecutively in arabic numerals.

In *equations* conventional symbols in accordance with the American Standards Association Letter Symbols for Meteorology should be used. If equations are written into the manuscript in longhand, dubious-looking symbols should be identified with a penciled note.

References should be listed on a separate sheet and numbered in the order in which they occur in the text; or if there are more than ten, in alphabetical order according to author. The listing should include author, title, source (if a magazine the volume, number, month, year, and complete page numbers; if a book the publisher, place of publication, date, and page numbers). If the referenced article is an independent publication, the author, title, publisher, place of publication, and date should be given. Within the text references should be indicated by arabic numbers in brackets to correspond to the numbered list.

Footnotes should be numbered consecutively in arabic numerals and indicated in the text by superscripts. Each should be typed at the bottom of the page on which the footnote reference occurs.

Illustrations. A list of legends for the illustrations should be typed (double spaced) on a separate sheet. Each illustration should be numbered in the margin or on the back outside the image area. To fit into the Review page, illustrations must take a reduction not to exceed 3½" x 9" (column size) or 7½" by 9" (page size). Map bases should show only political and continental boundaries and latitude and longitude lines, unless data are to be plotted, when station circles will also be needed. Usually the less unnecessary detail in the background the better will be the result from the standpoint of clear reproduction. Line drawings and graphs should also be uncluttered with fine background grids unless the graph demands very close reading. It is not necessary to submit finished drawings, as drafting work can be done at the time the paper is prepared for publication.

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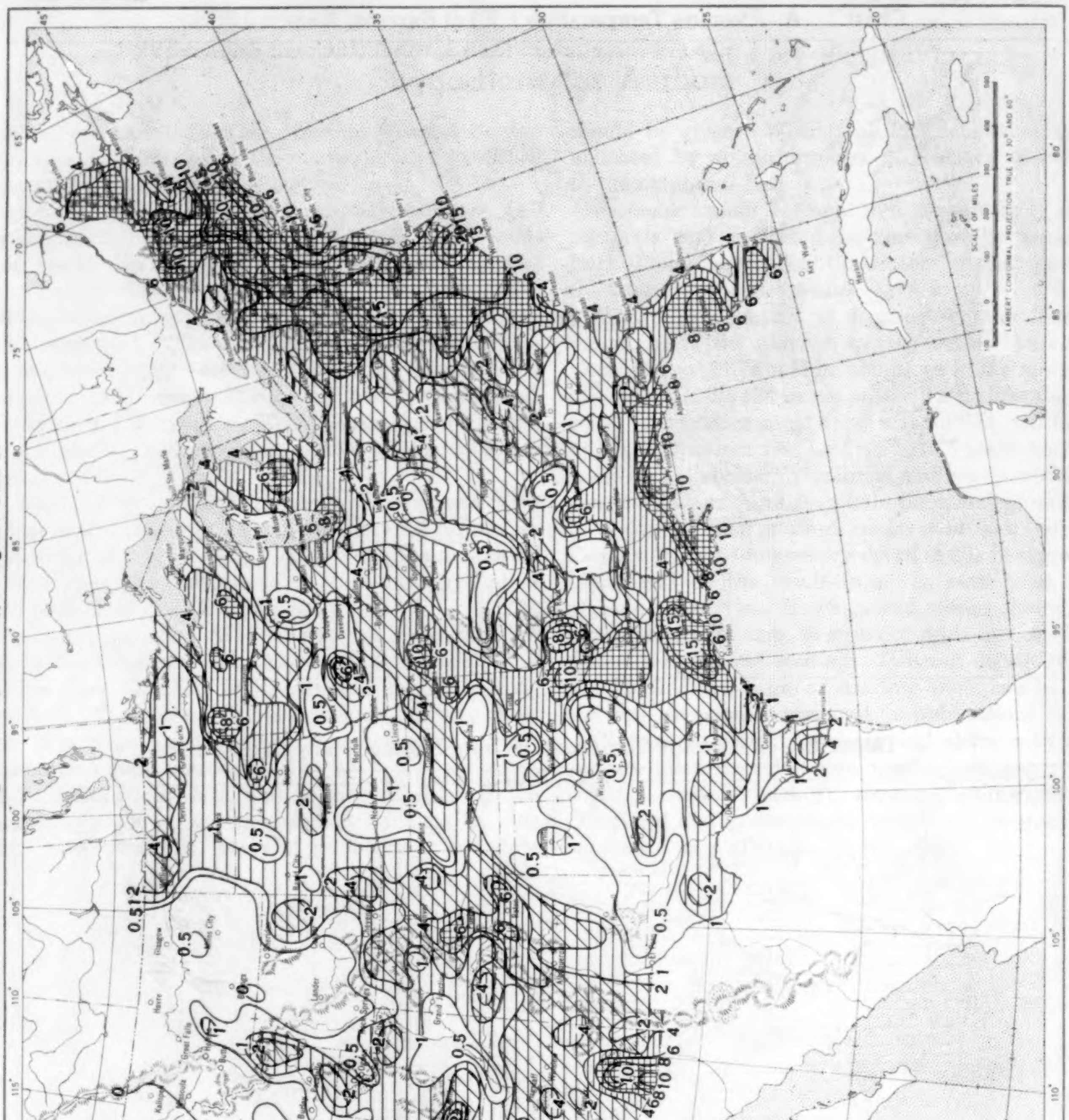
Chart I. A. Average Temperature (°F.) at Surface, August 1955.

B. Departure of Average Temperature from Normal (°F.), August 1955.

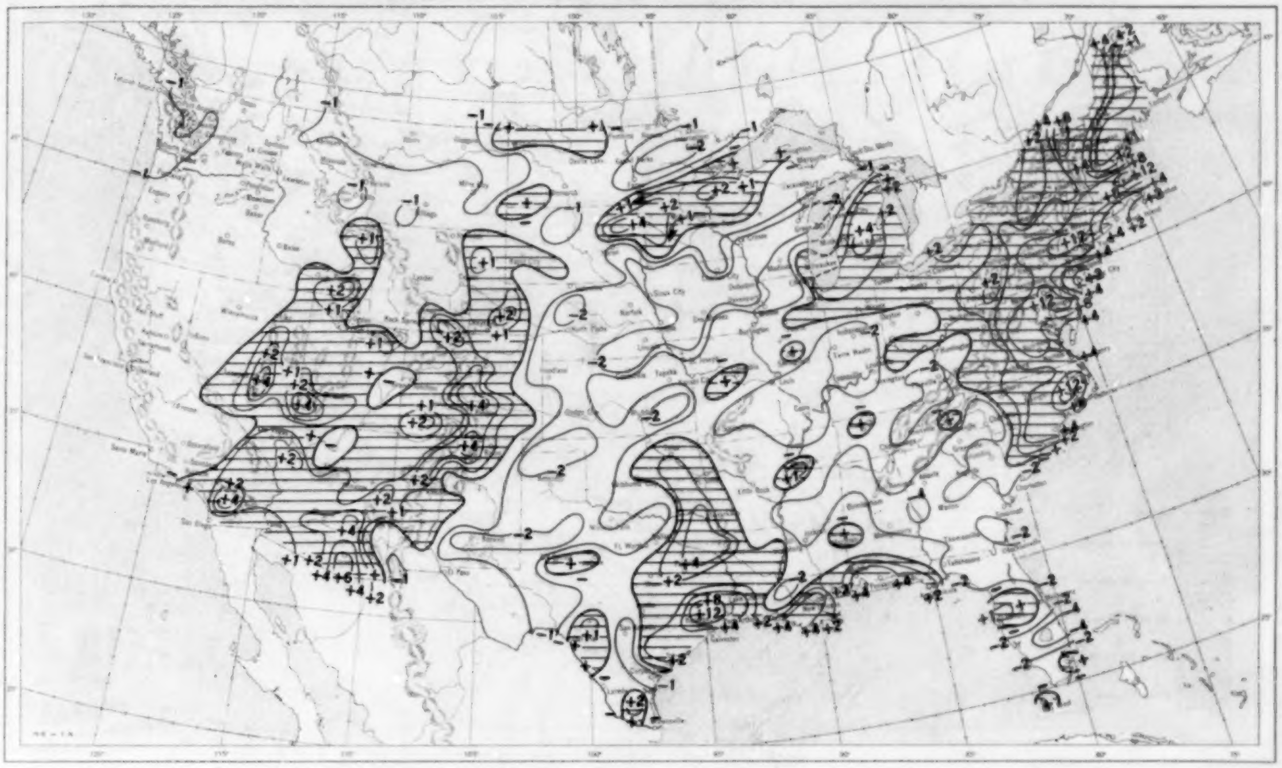
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), August 1955.

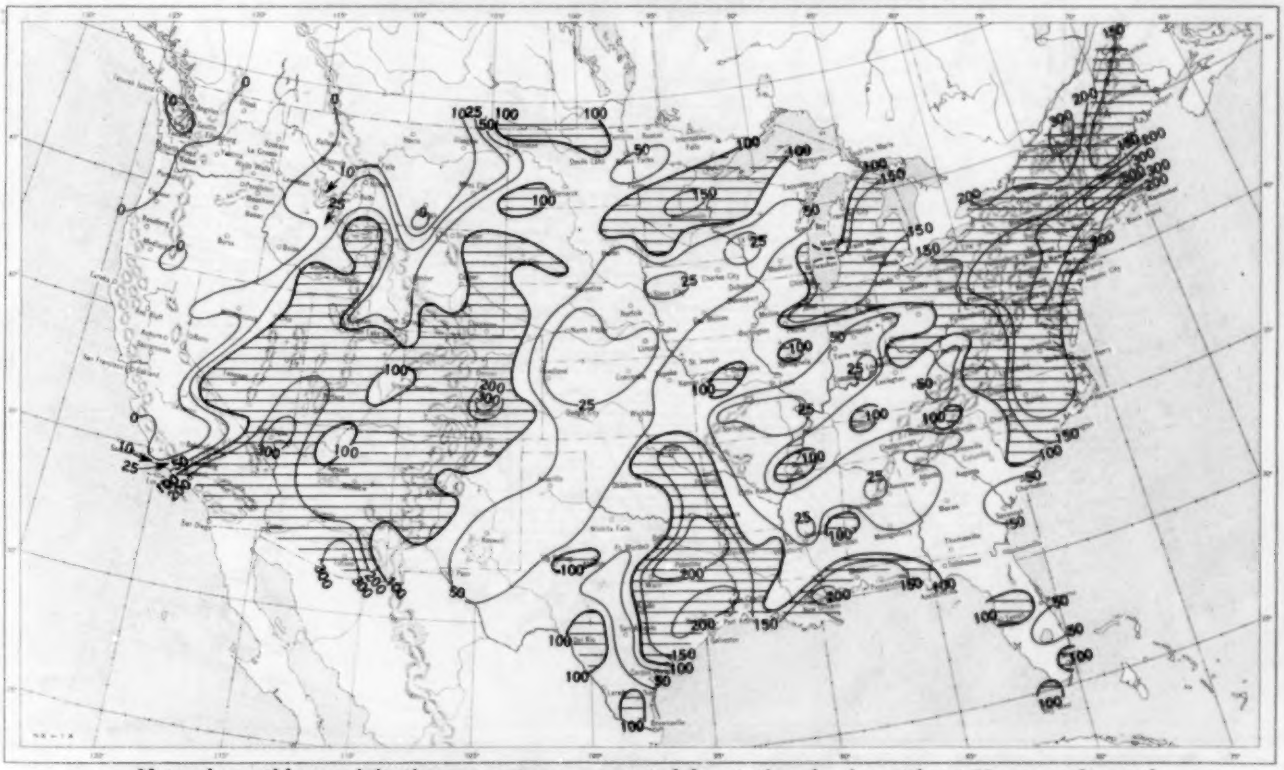


Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), August 1955.

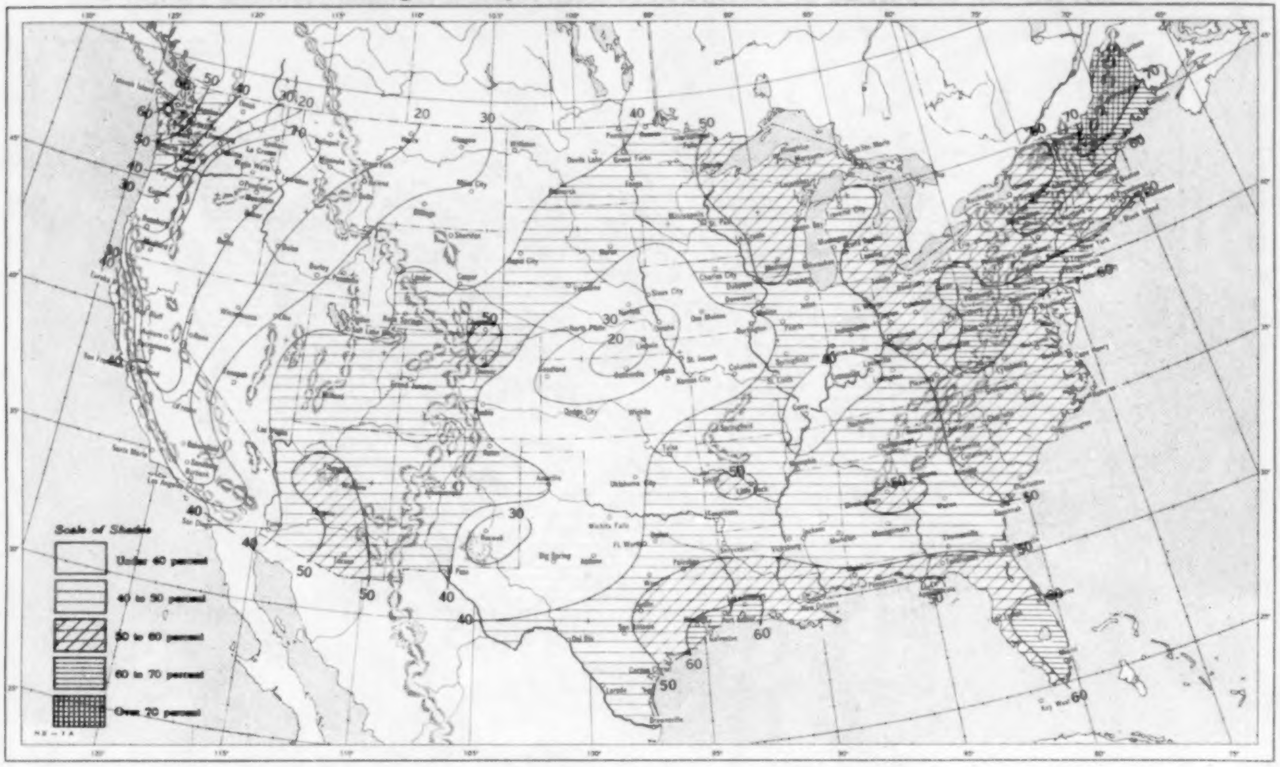


B. Percentage of Normal Precipitation, August 1955.

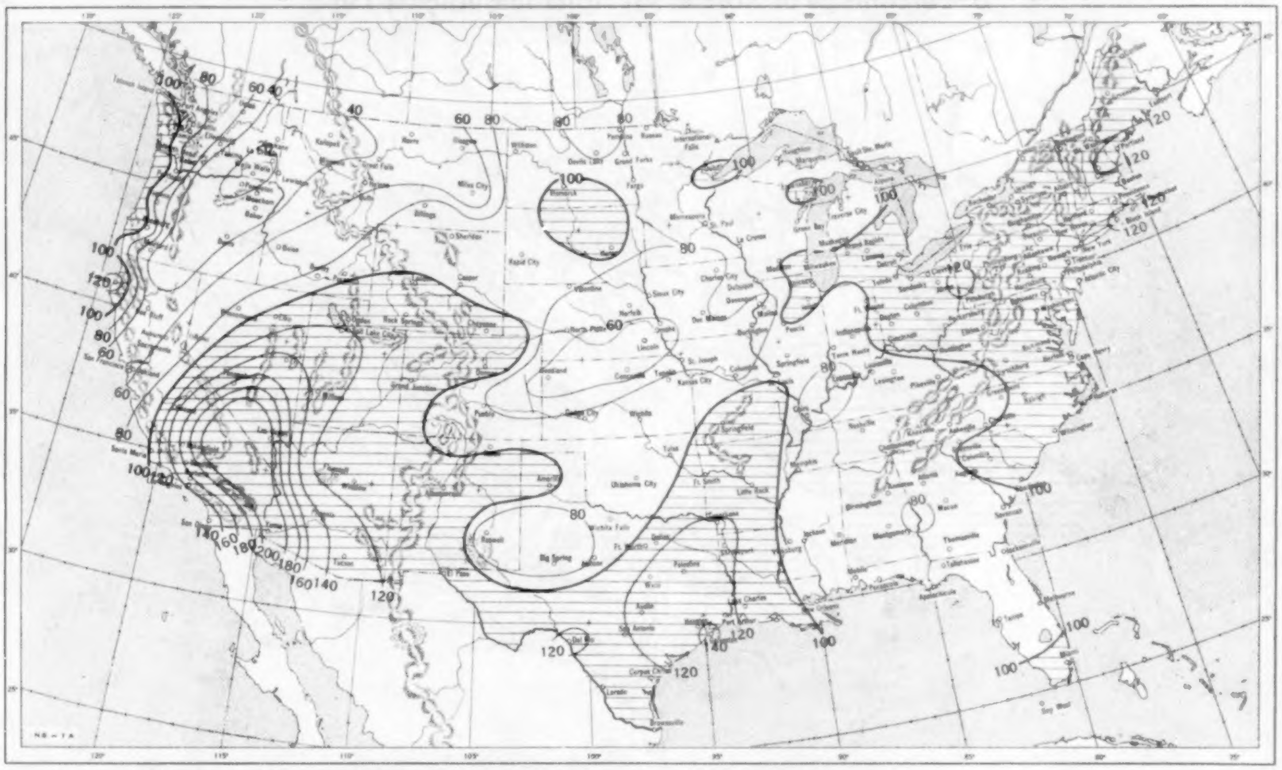


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, August 1955.

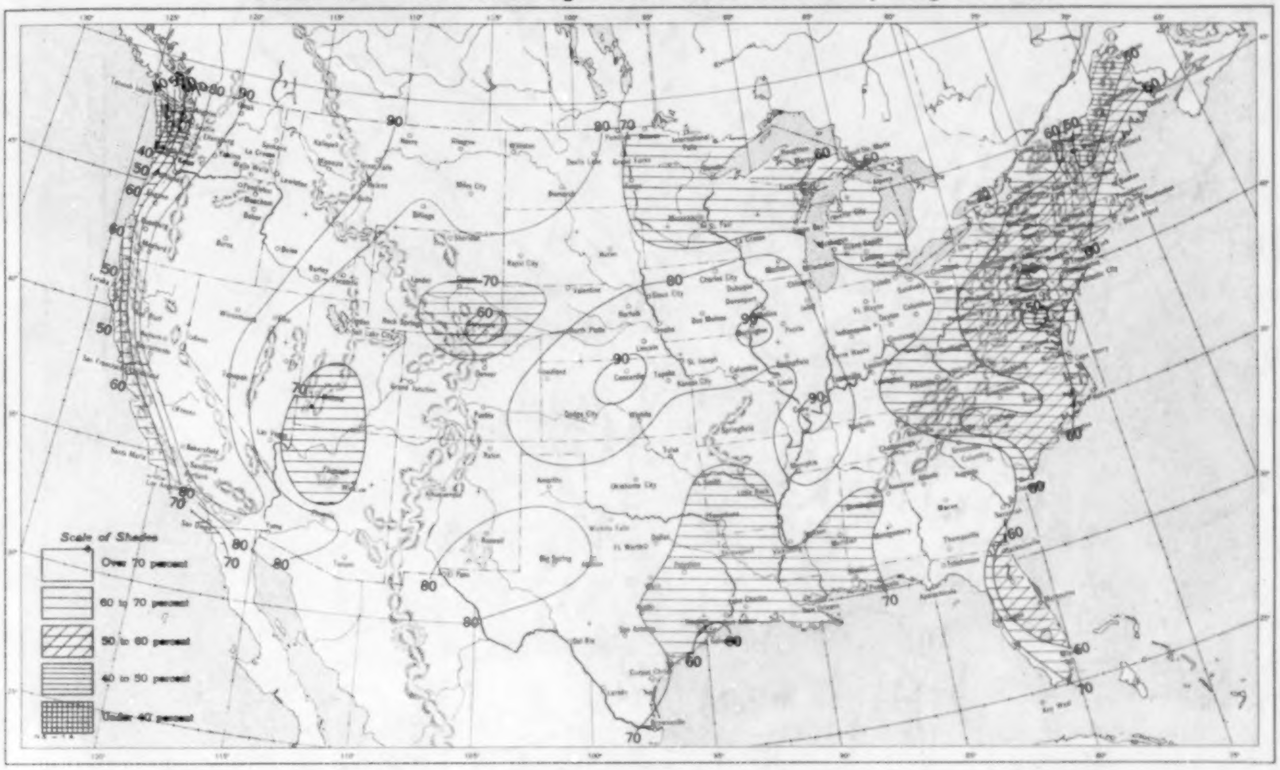


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, August 1955.

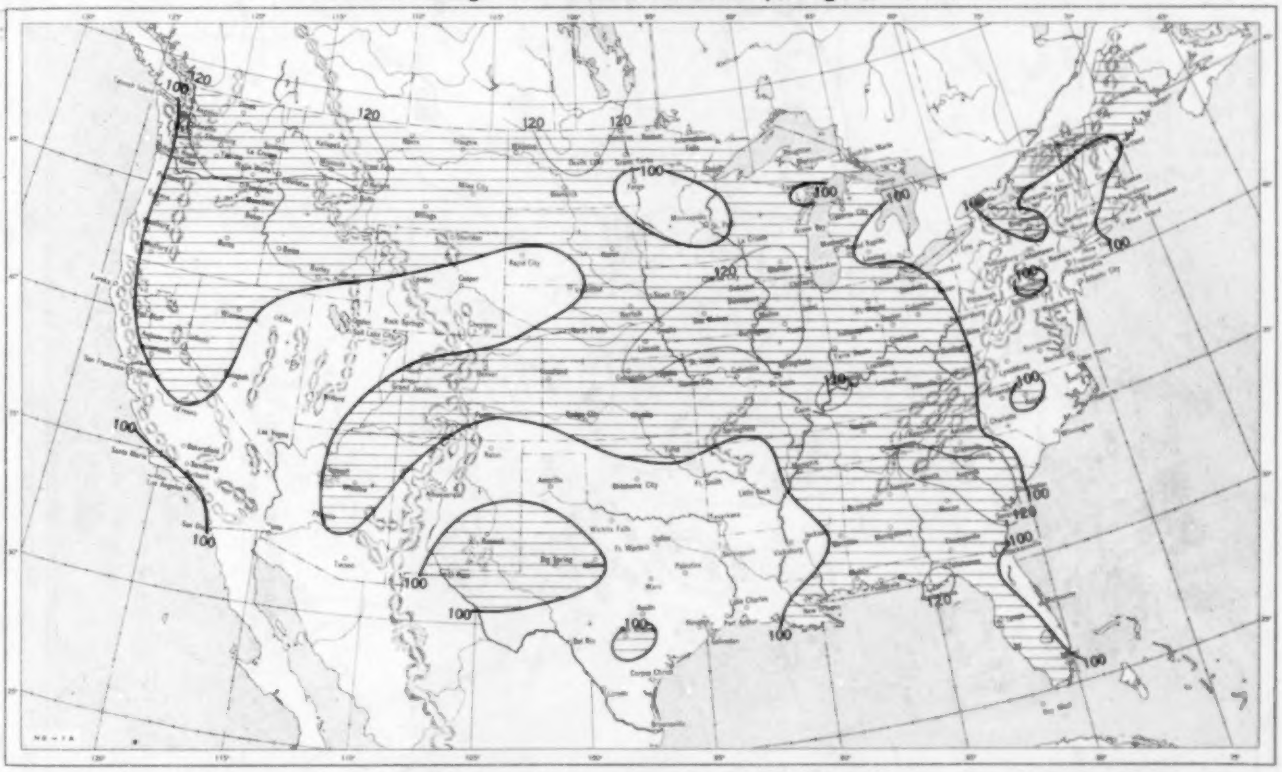


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, August 1955.



B. Percentage of Normal Sunshine, August 1955.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, August 1955. Inset: Percentage of Normal Average Daily Solar Radiation.

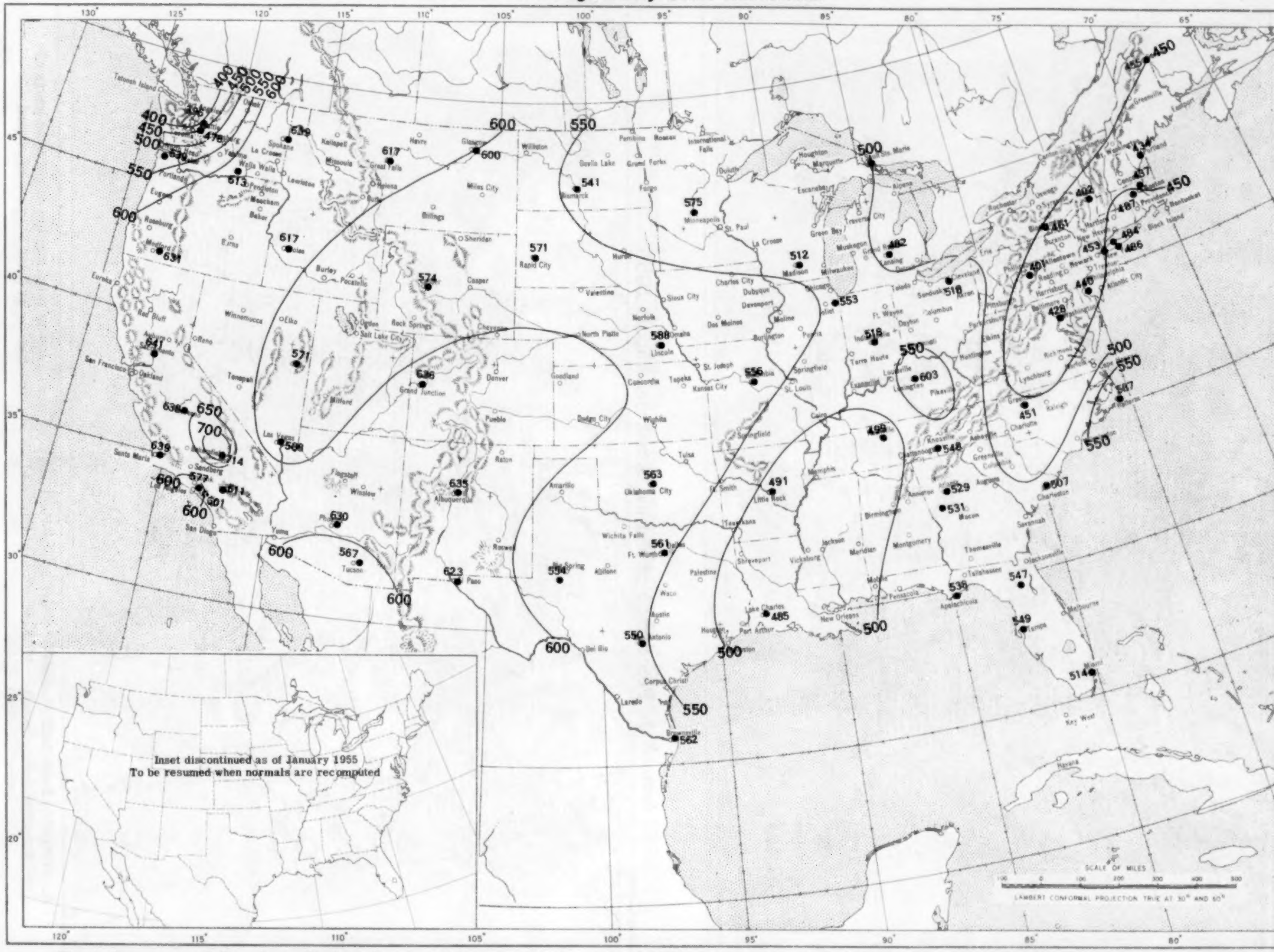
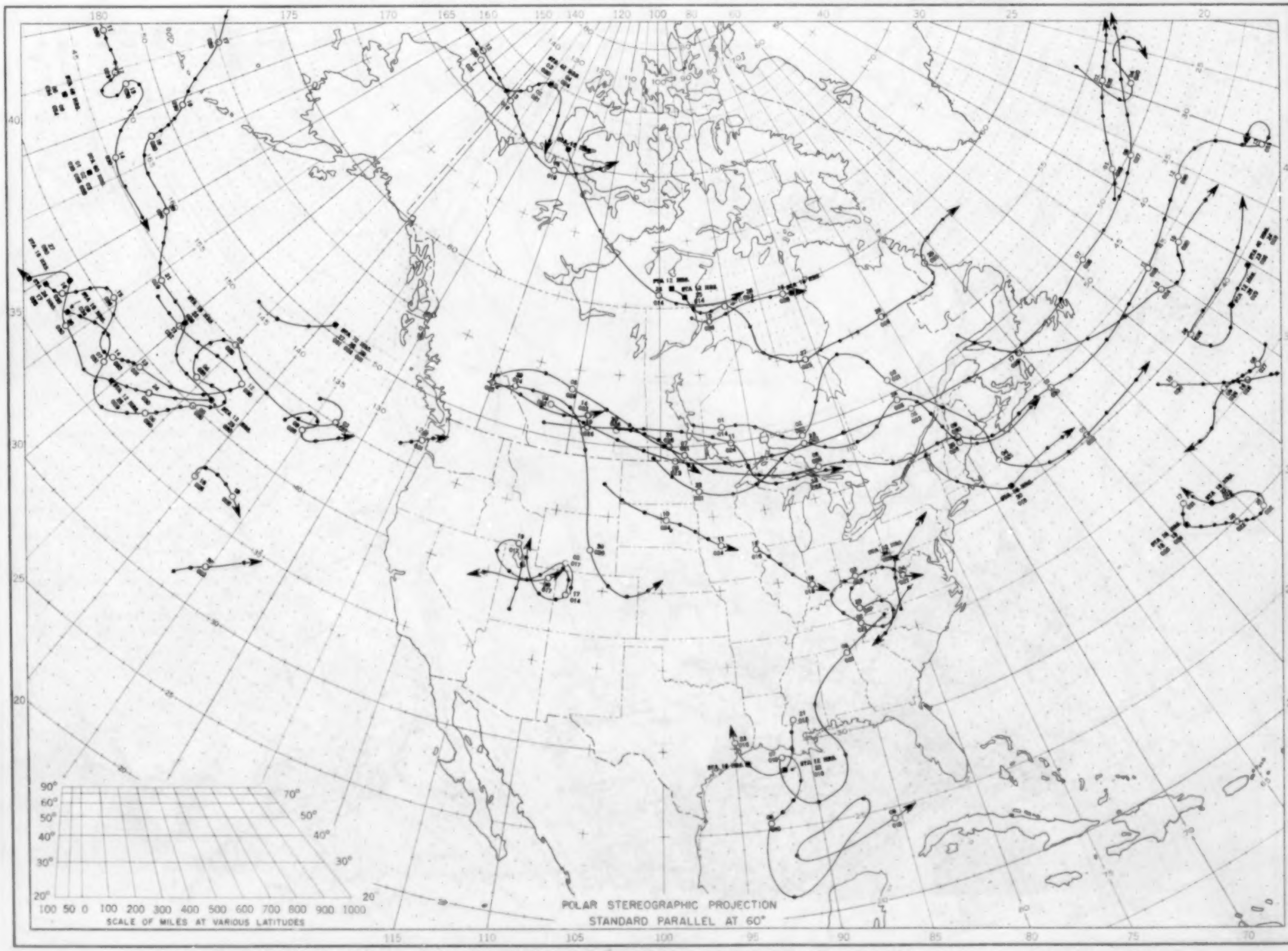


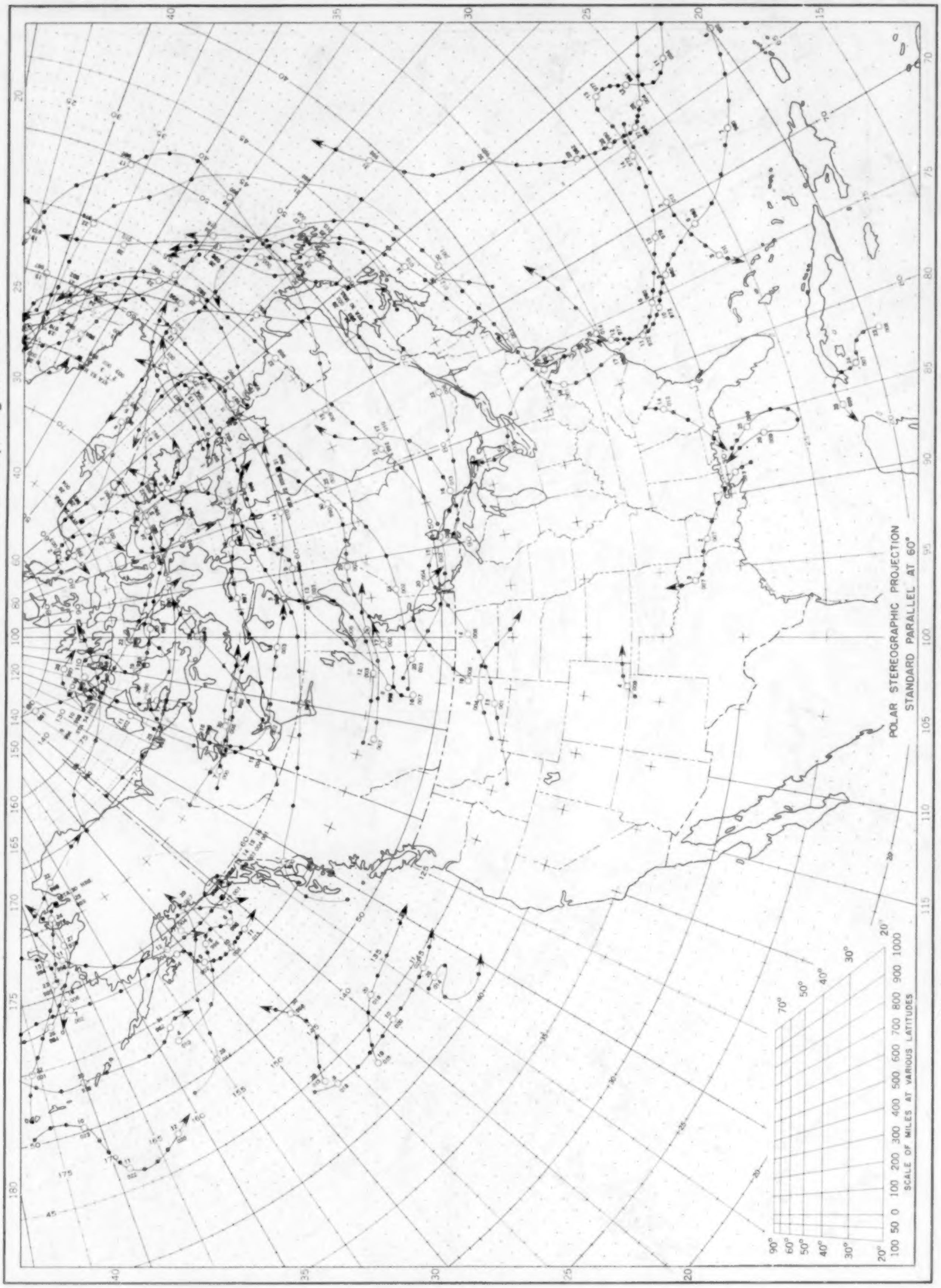
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, August 1955.



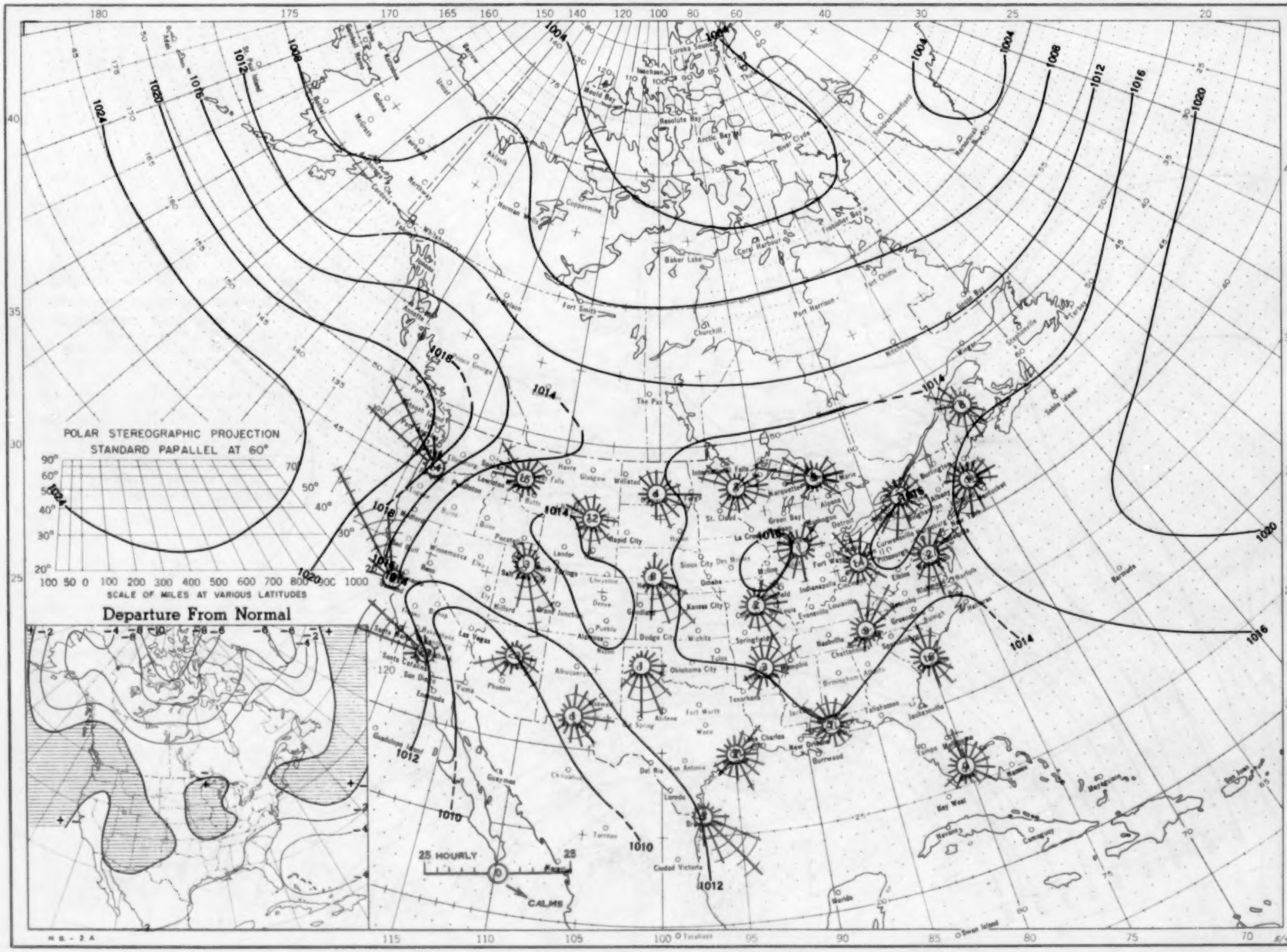
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, August 1955.



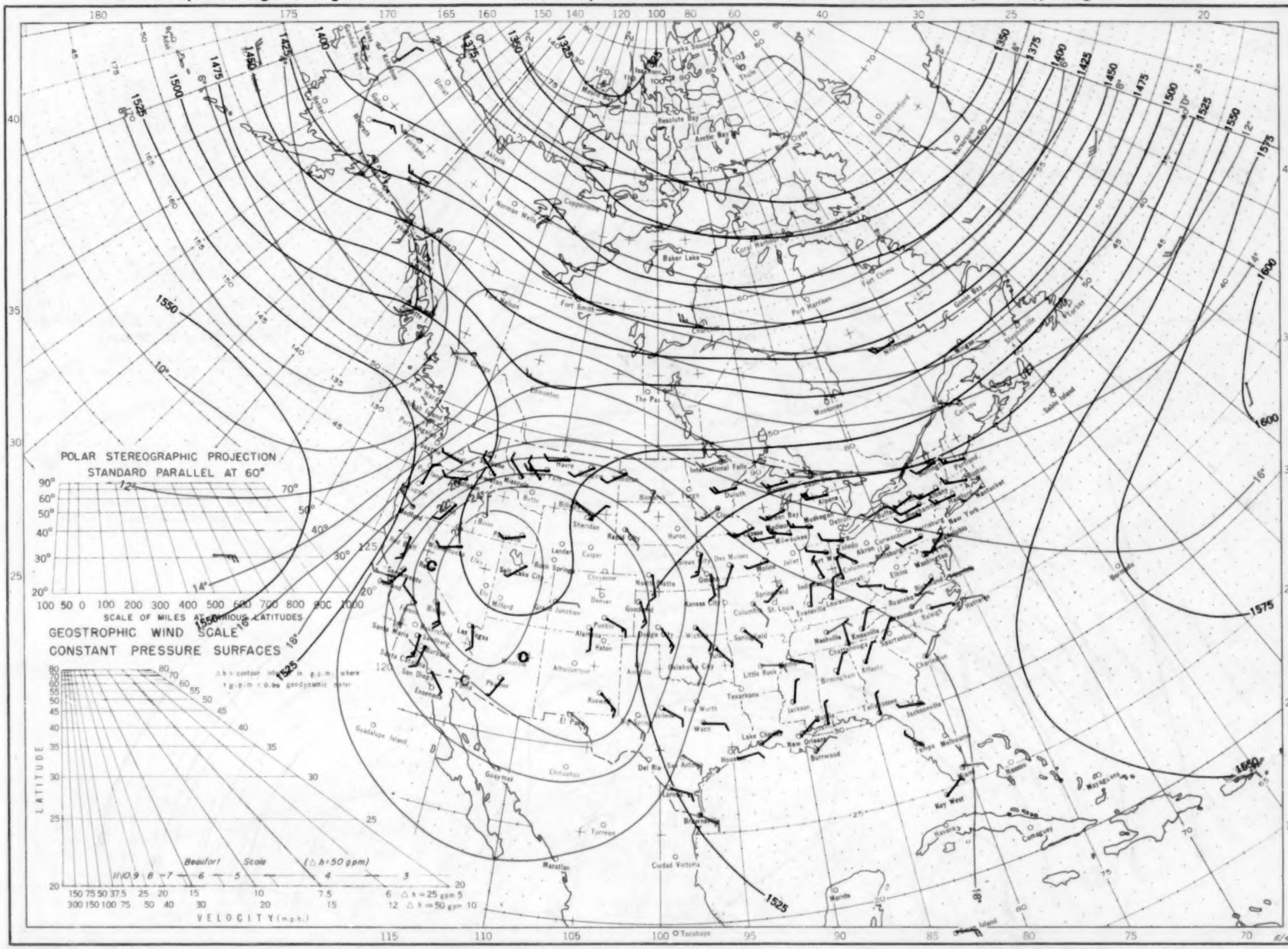
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, August 1955. Inset: Departure of Average Pressure (mb.) from Normal, August 1955.



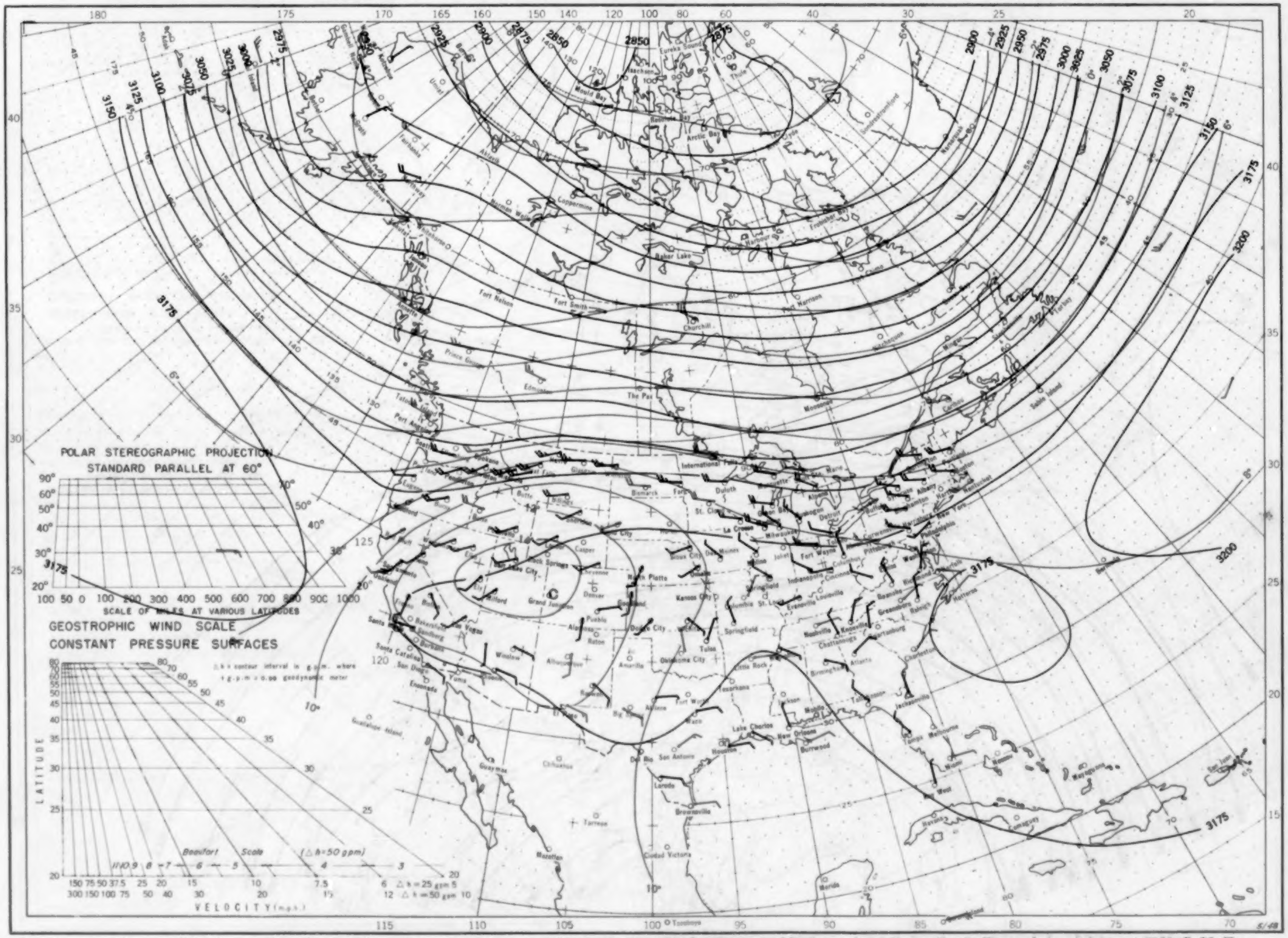
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), August 1955.



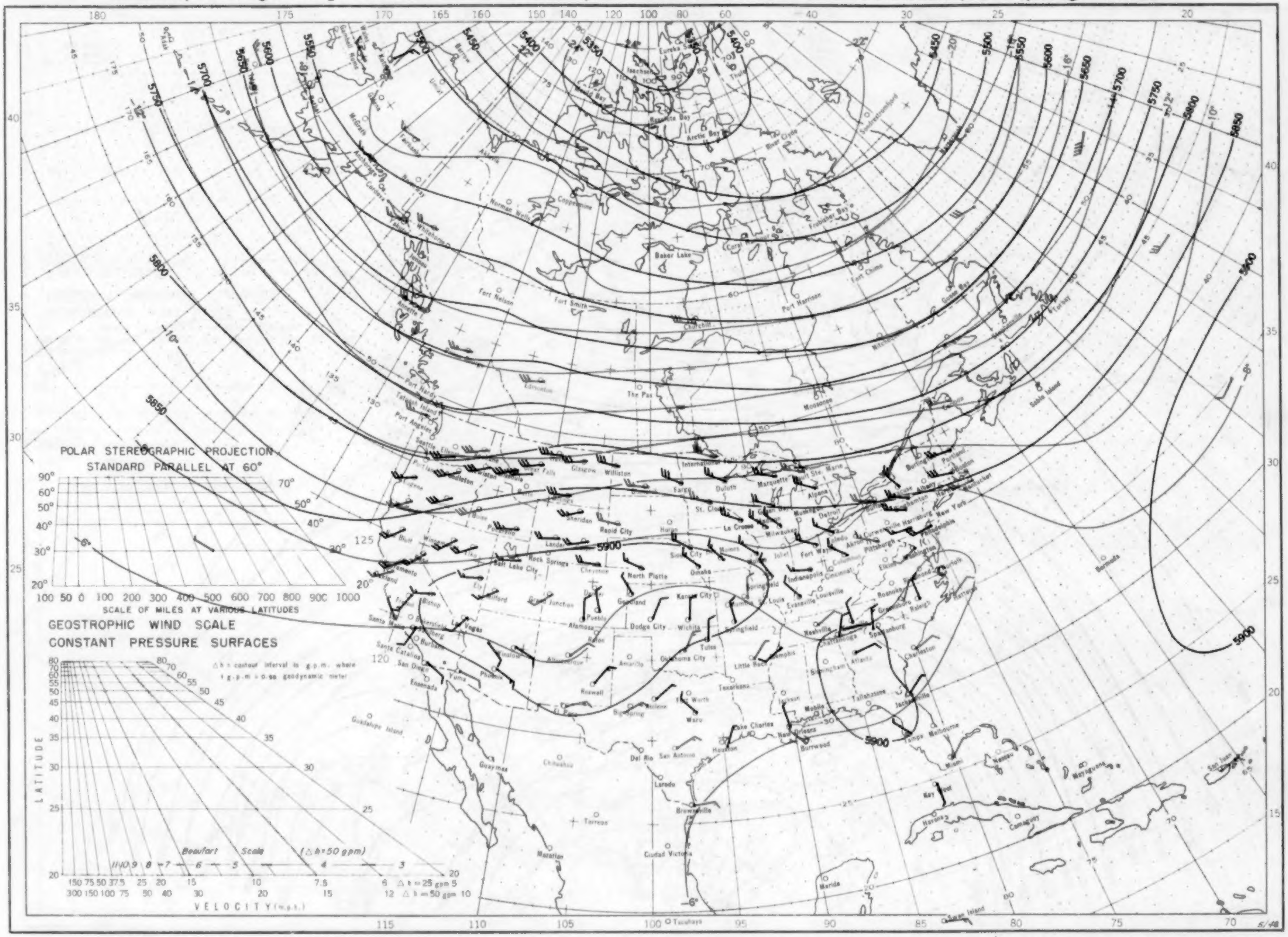
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), August 1955.



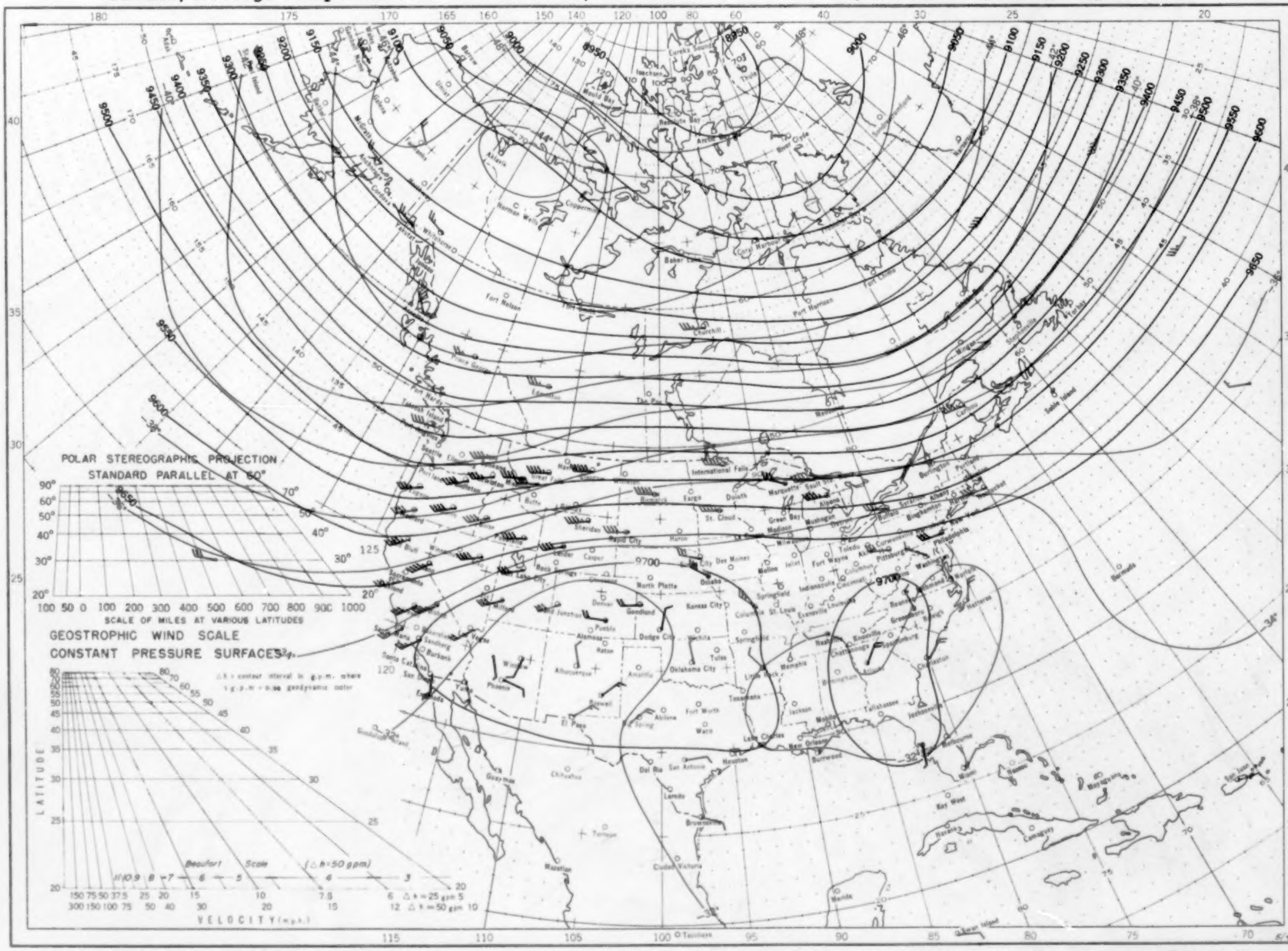
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), August 1955.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), August 1955.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.